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Geomorphology of the Rhône Delta

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INTRODUCTION AND ACKNOWLEDGMENTS

Deltas are interesting places. To the geologist they are enormous deposits of sedimentary rock. To the isostasist they are places where great loads accumulate and also possible agents of crustal readjustment. The agriculturalist regards many of them as unrivaled tracts of arable land. Historians chronicle their significance in the development of civilization. Conservation practices, mathematics, and engineering have been nurtured by their hydrographic problems. Geographers find manifold interests in deltas and someday will establish a subscience of deltography, to take its place alongside such disciplines as oceanography, limnology, and mountain geography.

The Rhône delta occupies a rather modest place among the great deltas of the world from the standpoint of area, geologic consequence, or rôle in history. It is not without interest in any of these regards however. Though compact, occupying but little more than 700 square miles, with flanking deltaic plains included, it is in every sense a typical delta. The Grand Rhône, Petit Rhône, and Mediterranean shores form a triangle, the Camargue, or Rhône delta proper, with symmetry in no sense inferior to that of the Nile delta. In its immediate vicinity lived some of the earliest of the known races of Europe (12). Its surface has exhibited a kaleidoscopic pattern of cultural change and evolution, much of which is dim in the perspective of history. Some of its inhabitants are represented today by only an occasional place name, some by archaeological fragments, while

others have left salient imprints in today's landscapes. Cultural and physical elements are in many cases so closely related in the Rhône delta that it has been felt advisable to depart from discussions of purely physical problems at times and interweave the text to follow with subject matter from several adjacent geographic disciplines.

Scientific investigation has by no means overlooked the Rhône delta. Herodotus was aware of it and mentions its inhabitants. Strabo devotes several pages to its topography, its peoples, and their customs. Various writers on down through the ages have considered it from so many viewpoints that one feels a bit presumptuous in adding to its literature. The bibliography present here makes no pretension to completeness but it is hoped that it may be useful. The writer has read all the papers listed and many others as well. From the geographic standpoint he considers especially valuable the classic researches of Charles Lenthéric (74; 75) and an excellent monograph by Pierre George (50). A valuable undertaking, well worthy of investigation by geographers, is, Les Bouches-du-Rhône, Encyclopédie Départementale, published by the Archives Départmentales, Marseille, in 1914, under the direction of Professor Paul Masson. The third part of this monumental work, Le Sol et les Habitants (99), might well be used as a model for geographic monographs of other regions.

The writer wishes to acknowledge his deep debt of gratitude to President Wallace W. Atwood, of Clark University, for the gift to the Association of American Geographers which made this study possible, to Professor Léon Lutaud, Faculté des Sciences, Paris, for many helpful suggestions, to Professor Georges Denizot, Faculté des Sciences, Marseille, who joined the writer in the field and offered many helpful ideas, to M. Moulias, Entrepreneur, Trinquetaille, for subsurface information, and to M. Léopold Laupie, Arles, whose intimate knowledge of the country and able assistance made it possible to visit not only the more accessible parts of the delta and its surroundings but to explore many of its remotest trails as well. While individual acknowledgements to the many persons who have assisted, especially in the field, are impossible, the writer cannot let this opportunity pass without paying tribute to the people of the lower Rhône region for their kindliness and to their intelligence and interest with regard to problems of natural and physical science.

PHYSICAL REFERENCE FRAME

Regional Geology

Preparations for the Rhône valley from Lyon to the Mediterranean date from the end of the Paleozoic (7–288), when synclinal structures were

initiated between the Massif Central, on the west, and the Alpine Zone, on the east (59–668). Mesozoic estuaries at times extended about half of the distance to Lyon (111). Tertiary folding accentuated the synclinal structure and throughout much of the Cenozoic the Rhône valley had the appearance of a small Adriatic Sea (43–729).

The Eocene witnessed the deposition of flysch sediments in waters which varied from time to time in possessing littoral, estuarine, or continental characteristics (37–422). Oligocene times found brackish waters dominant in the lower Rhône valley (7–229). Miocene submergence converted the valley into a beautiful fjord with branches extending up such tributary valleys as Drôme, Isère, Savoi, and Ain. Excellent molluscan faunas may be recovered today from the sediments deposited in this drowned valley system (74).

The folding which now dominates the structures of the existing mountains of Provence occurred in the late Miocene (39–41). There has been considerable debate as to the exact time and some of the latest Miocene is today horizontal (9–336; 10–638; 23; 37–444; 103; 118), but such questions need not concern us here.

The last major invasion of the Mediterranean northward along the Rhône Valley occurred in the Pliocene, when waters extended to within 20 kilometers of Lyon (7–229; 45; 47–178; 59–668). The shells of animals which lived in this fjord are now incorporated in clays which attain a thickness of 100 meters near Valence. The fauna was closely related to those known from the Caspian, Danubian basin, and the Orient (37–445).

While Quaternary history has been described chiefly in terms of erosion, field evidence clearly indicates several important alternations between erosion and sedimentation. Benches on valley sides have been considered as indicative of old, high-level seas by most writers (55–634; 92; 93; 101; 102; 109; 113). Such seas are generally presumed to have lowered, step by step, during the course of time (84–232; 85–665). The highest benches have been interpreted as Tertiary in date of origin and some may be (49; 56; 66; 68; 72; 81; 82; 116). To the writer the main terraces are Quaternary in age and are most readily explained as the result of oscillations in sea-level caused by variations in the volume of continental ice-caps (120). Their preservation at levels above flood plains is the result of epeirogenic uplift. Each great increase in glacial volume lowered seas, and valleys were cut to the base levels thus established. Each retreat in glacial dimensions raised seas and the valleys were alluviated, building through sedimentation extensive flood plains and deltas. The flats thus built became terraces when seas again dropped. Slow uplift raised the flats of one stage above the sea-level of the next cycle of alluviation and thus preserved the terraces. Dif-

fering interpretations have been advanced by others (2; 18; 19; 57; 89; 122; 123; 128).

The Recent is a time of interglaciation. In comparison with much of the Quaternary its glaciers are unimpressive and seas are at relatively high levels. It is thus a time of alluviation, a fact which may be seen along the seaward parts of practically all valleys. The relationships shown in the Rhône delta region (Fig. 1) are almost universal (83–87; 115–2; 119; 121).[1] Valley floors are flat because they are being alluviated and the contrast between flood plains and valley walls is sharp both because of abruptness in change of gradient and in type of material. One need not be a trained geomorphologist to find the exact edge of the Vistre flood plain. It is the boundary between an extensive alluvial flat and a hill that rises sharply toward a Pleistocene terrace. This hill owes most of its sculpturing to the erosion which took place just before the Recent began, when seas were low and the ancestral Vistre was flowing down an accentuated valley. The hill is composed chiefly of gravel in this particular case and the adjacent flood

FIG. 1.—Vistre flood plain from Pleistocene valley wall near Mas Melet.

[1] All delta place names mentioned in this report appear on the index maps, Figs. 12 and 13.

plain consists chiefly of clay and silt. The contact between gravel and finer materials is sharp so that its depth is readily ascertained by boring into the flood plain and the configuration of the pre-Recent valley may be determined readily. Almost within the field of view of the photograph are the wells of Aigues-Mortes, where the Recent alluvium is at least 150 feet thick, so it is reasonable to suppose that the valley upon whose side the picture was taken originally went on down to some such depth as that. Alluviation has been so active that erosion has been overwhelmed in this particular case, for no alluvial apron flanks the exposed slope. This is an example of alluvial drowning, the outstanding result of Recent sedimentation in most valleys.

The alluvial nature of valley flats and terraces in France was recognized as early as 1831 by Boubée (17).

Topography

The lower Rhône valley is an excellent example of alluvial drowning. Its floor is flat and alluvial. Its walls rise sharply and consist of hard rock or relatively coarse terrace deposits. Where the walls are composed of Mesozoic or earlier rocks they exhibit structures indicative of intense folding and dislocation. Early Tertiary valley walls reveal rather pronounced

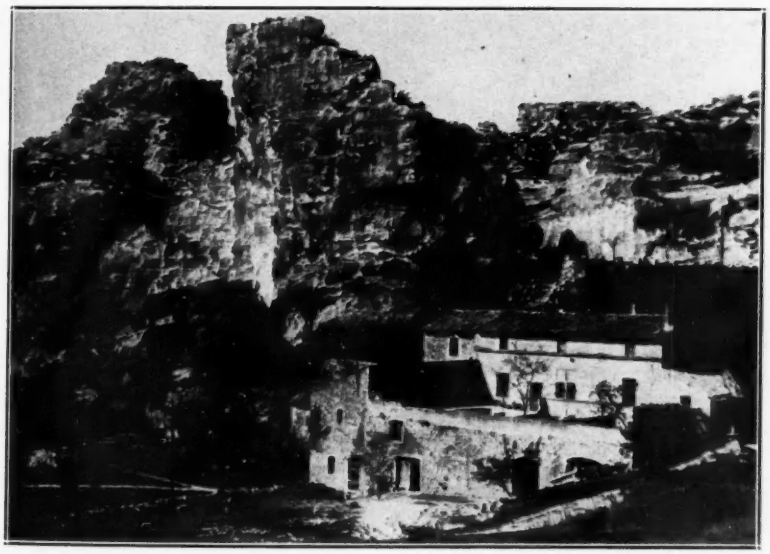


FIG. 2.—Barren hills of Miocene (Burdigalienne) marl, near les Baux.

dips as a rule. Dips are gentler in the late Tertiary and Quaternary valley wall deposits. These occur chiefly southward, toward the delta.

Landscapes in the immediate hinterland of the valley vary a good deal according to type of bedrock and exposure. Toward the southern end of the valley the older rocks of hills and mountains are mainly limestones and marls. Some of these develop karst topography. Some weather into bizarre, barren crags (Fig. 2). Effective seepage, intense evaporation during the spring, when the mistral blows southward with force and fury, and a long hot summer combine to produce landscapes far drier in appearance than we might expect in a region receiving from 20 to 30 inches of rain, distributed through as many as 100 days per year. Conspicuous patches of bedrock typically form white scars on hills otherwise covered with dark- or gray-green dwarf forest, chaparral or maquis, especially on southward slopes (50–227). The more sheltered northward slopes exhibit tall conifers and large hardwood trees along streams and, in some places, over extensive areas toward the summits.

Many of the late Tertiary formations are poorly indurated and tend to erode into badlands (Fig. 3). This is particularly true of continental

FIG. 3.—Badland topography at les Fosses des Fournès in Pliocene (Plaisancienne) clays.

deposits formed under floodplain or shallow estuarine conditions along the Rhône valley. Marine formations are more consolidated and tend to form residual hills which ordinarily support rather dense stands of maquis or garrigue, with Kermès Oak.

Pleistocene surfaces are mainly terraces covered by gravel or loess-like silt. Gravel flats are especially barren and desolate in their natural state (Fig. 4). Seepage is so effective that surface run-off is negligible and

FIG. 4.—Gravel surface of la Crau, a Pleistocene terrace, near Cabane du Ventillon.

water courses are practically non-existent. Erosion occurs only along the marginal scarps and little has taken place during Recent times, except where artificially induced. More favored parts of such surfaces and abandoned agricultural land support low live oaks. Irrigation has transformed many terrace surfaces especially where the cover is less gravelly, into productive fields. Gravelly tracts have been converted from desolate wastes into vineyards (Fig. 5).

Regional Hydrographic Net

The hydrographic net of the Rhône delta and its vicinity is shown in Fig. 6. All natural and artificial water courses of sufficient consequence to be shown in blue on the Avignon, Digne, Marseille, and Montpellier sheets

FIG. 5.—Vineyard on gravelly Pleistocene terrace a short distance south of Jonquières.

of the 1 : 200,000 map of France constitute the net as presented. If sheets of the 1 : 50,000 map had been used the density would have been intensified notably but pattern characteristics would have been changed but little.

Mountainous and hilly tracts are designated, Garrigues, Ventoux, Vaucluse, Luberon, Costes, Fare, Étoile, Nerthe, Montagnette, and Alpilles. A rich synonymy exists for many of these names.

East-west structural trends are apparent in the drainage patterns of several ranges, the best examples being Alpilles and Luberon. From rather linear summits streams descend in parallel arrangements toward the north and south. Shorter, steeper slopes face the north. Less regularly developed patterns reflect the plateau-like structures and surfaces of Costes, Fare, Étoile, and Nerthe. Structural doming in Châine des Costes accounts for its radial drainage net, something also true, but to a lesser degree, in l'Étoile and Châine de la Nerthe. La Montagnette is a relatively flat-topped island of Cretaceous bedrock but a slight southeastward inclination of its summit accounts for a number of small, parallel streams leading in that direction.

The region designated Garrigues is a marginal Tertiary and Cretaceous piedmont of the Cevennes. The Gardon, Vidourle, and other streams have

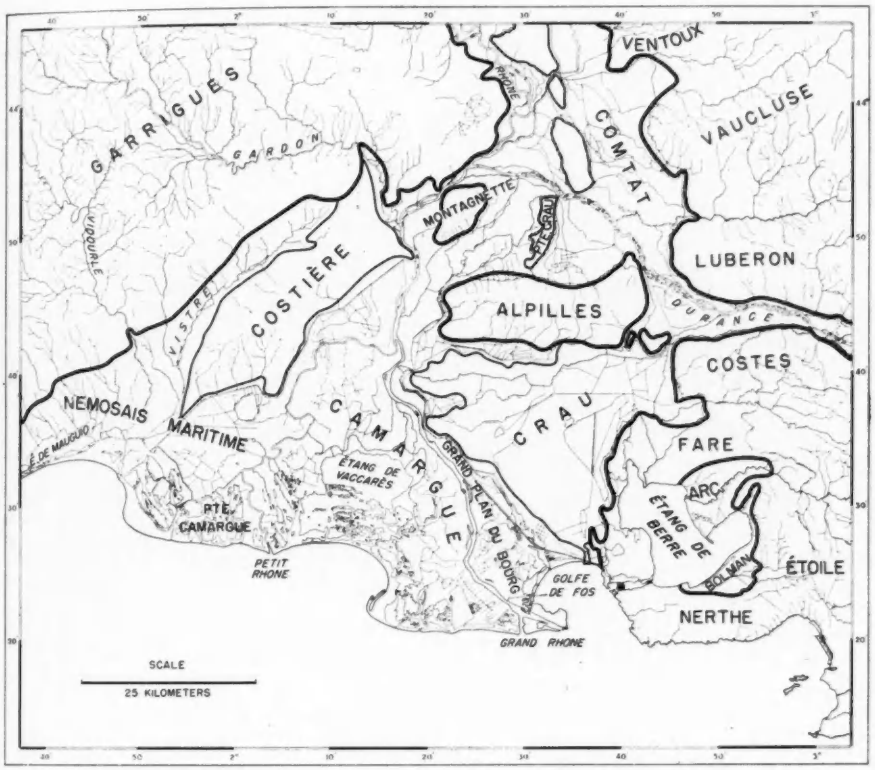


FIG. 6.—Hydrographic net of the Rhône delta and its vicinity. Boundary lines separate physiographic units which have been given characterizing names. The heavier boundaries lie between hilly and mountainous territory, on one hand, and Pleistocene terraces and Recent alluvium, on the other. Only the major rivers have been designated by name.

developed dendritic patterns strongly modified by northeastward structural trends in bedding and folding. Karst topography is developed in many of the limestones, one case of which stands out clearly in the centripetal pattern of Ancien Étang de Pujuat, toward the northeast.

Gravel covered plateaus include Costière, Crau, Petite Crau, much of Comtat, and the mesas east of the Rhône and north of la Petite Crau. Aside from the southward slopes of the southern Costière, where steep gradients have favored dissection through gravels and into rather impermeable Tertiary formations, these surfaces exhibit a general absence of streams, a con-

sequence of rapid seepage into gravels. The drainage net of the Crau is almost wholly artificial, being fed by waters from the Durance which are conducted through the Pass of Lamanon (Fig. 7) in master canals (11; 129). The gravel surface of the Crau extends through this pass and continues up the valley of the Durance as a terrace (11–82). During Recent times the Durance has become entrenched below this old outlet and now follows a course north of the Alpilles to Avignon. Two étangs of the Crau are nourished by subterranean flow (11; 129). Several étangs between the Crau and Étang de Berre are developed in the basins of a karst region.

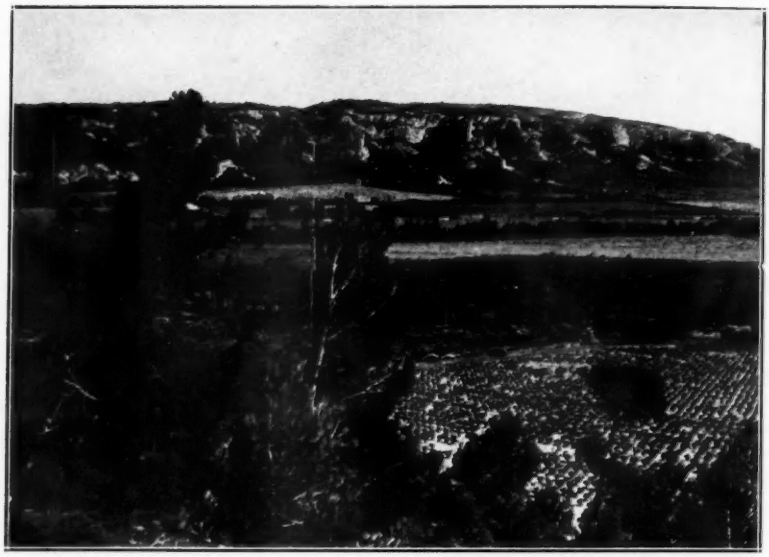


FIG. 7.—The Pass of Lamanon, between Châine des Costes, whose Miocene outcrops are shown in the view, and le Defends.

The gravel plateaus are Quaternary terraces (24–406). In Provençal most of them are known as craus. There are some interesting theories regarding the origin of this word (97–189). Bochart believes that it has been derived from Hebrew through the Greek χεραυνός, in which case it is related to the Latin *cravus*, (*cravis, gravum, grava, grève*), French *gravier*, and English *gravel*. Arguments have been advanced, however, that crau comes from the Celtic *craïg* (*crag, krag*). The word was first used in its present form and connection in the 11th century, in describing certain imperial privileges granted to the Church at Arles.

La Crau ordinarily means specifically the whole inclined surface which forms a triangle with apex at Lamanon and base between Arles and Fos (26). Individual parts of this surface have received such names as Crau d'Arles, Crau sur Durance, and Crau de Mimaras. The southern part of la Costière is often called the Crau of St. Gilles and continuations of the same surface westward are known as the Crau of Languedoc. Various detached terrace remnants bear individual names, such as la Petite Crau. Any terrace, mesa, or Quaternary surface is likely to be called a crau if it is gravel covered. If wholly capped by finer sediments it is called something else, quite commonly a plaine.

Recent alluvial surfaces in Fig. 6 include the flood plains of the Rhône, Durance, Arc, and Vistre, the deltaic plains of Nemosais Maritime, Camargue, Petite Camargue, Grand Plan du Bourg, and the isolated plain of Bolman, east of Étang de Berre. In addition to these are such minor features as narrow fingers of flood plain which extend into the hilly tracts, especially along the Gardon, and a considerable part of Comtat. The exact differentiation of surfaces in this latter region is rather complex and would serve no useful purpose here.

The torrential nature of the Durance is proverbial.[2] In Fig. 6 it is expressed by numerous small islands along the channel. These indicate either sand or gravel bars which the stream shifts freely and whose materials it carries forward in great quantity. In the case of the Durance the material is chiefly gravel (Fig. 8). The whole lower course exhibits braiding, the result of an oversupply of coarse material. Stage differences may be appreciated from recorded values of discharge: 1,906 cu. ft./sec. (min.), 12,260 cu. ft./sec. (av.), and 326,000 cu. ft./sec. (max.). In times of flood it may carry more water than all of the other streams in France combined (98–97). The maximum floods occur in May (21–459). A volumetric increase sufficient to supply a flow 170 times greater at maximum than at minimum stage or an increase of 18 times as much water at maximum over average stage provides an adequate agency for the transportation during flood of huge blocks of material which become stranded and rest in the bed at ordinary stages. In the case of the Durance such materials are available in the form of gravel and so we find the whole channel dominated by them.

The Rhône is not only too small to absorb and smooth out Durancian characteristics but it also has similar "hydrologic monsters" tributary to it at other points along its lower course, notably the Ardèche, Gardon, and Érieux, all of which are subject to rapidly rising floods, called cévenoles. The Ardèche rose 3.55 meters in 4 hours, Oct. 8, 1907 (21–460). At

[2] Lou Mistraù eme la Durençò Parlement, mistral et Durance
Gaston la mita de Prouvençò. Sont les trois fleaux de Provence.

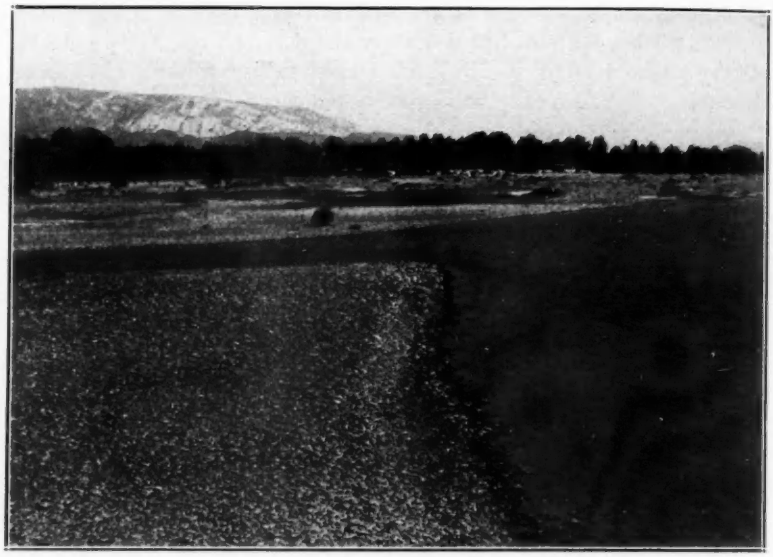


FIG. 8.—Durance channel near Mallemort. Gravel bars contain boulders up to a foot in length.

Valence the Rhône flooded its 5 to 6 meters terrace in 1856 (44–129) and in 1804 rose 6.5 meters above its low stage (77–220). Its absolute maximum discharge at Beaucaire was 13,000 cu. m./sec., in 1840 and its minimum 360 cu. m./sec., in 1921 (21–459). In lowest and highest stages it practically duplicates volumes of the Nile (6–16). Its ordinary annual discharge is greater than that of the Seine, Loire, and Garonne, combined (105–316). On 320 days of the average year it stays below mean stage, the remaining 45 days, chiefly late spring and early summer, find it higher. At places its current attains a velocity of 15 km./hr. (32–237). Most authorities agree that the word "Rhône" means rapid or swift, so that the river derives its name from the nature of its current.

A sharp contrast in channel pattern occurs on either side of the Durance confluence. Downstream the channel exhibits many obstructional islands within the channel, braiding caused by the overload contributed by the Durance. Upstream the islands of the flood plain are entirely different. They are larger, parting channels by several kilometers in many cases. These are the result of alluviation under slack water conditions and resemble the distributary channels of a delta. The contrast arises from the fact that

the alluvial deposit of the Durance is a cone which has blocked the Rhône valley. The slack water alluviation occurs on the upstream side of the cone, where gradients have been reduced. The braided channel downstream occurs on the relatively steep slope of the Durancian cone and results chiefly from clogging of the channel by sand and gravel. Gradual adjustment occurs farther downstream, where the islands become smaller and less numerous. It is accompanied by a transition from gravel to sand as the dominant material on bars.

In the delta region gradients are low and the Rhône has undergone an interesting history of channel changes, to be described later. Each channel, whether active or abandoned, is flanked by natural levees and these divide the delta into numerous basins in which the drainage conditions are poor. An elaborate system of drains (drailles, égouts) is necessary for the reclamation of land and a somewhat less developed system of canals (béals, roubines) furnishes water for irrigation. The artificial drainage net contains many straight lines but abandoned stream courses have also been used, especially for irrigation canals, and thus many channels which are essentially artificial in function reflect natural patterns. These conditions obtain not only in the Camargue but also along the deltaic plains on either side. The Grand Plan du Bourg and Nemosais Maritime contain long, straight navigation canals. Small nets of canals toward the coast are salines, producing salt from the evaporation of Mediterranean water. For many centuries this has been a profitable activity for the State. It is now of consequence in chemical industry (Fig. 9).

To the west of the delta the coastal plain is essentially an alluvial apron. Heavy sedimentation by the Vistre, Vidourle, and other streams heading in the hills of Languedoc has provided a surface with sufficient slope to keep water courses relatively straight, evenly spaced, and parallel. Good samples occur just north of Étang de Mauguio. The Vidourle fails to reach the sea during low stages but its floods have at times attained values 30 times greater than the discharge of the Seine at Paris (98–107). Alluvial aprons built by such streams are not unlike those of the arid parts of the American Southwest.

CHANNEL HISTORY

Age of Channels

Any surficial channel, whether active or abandoned, is "modern," rather than "Recent," in a geologic sense. According to most authorities "Recent" began between 20,000 and 30,000 years ago (28–725; 95–1168; 112–266). No surficial channel has maintained itself for more than a small fraction of that time.

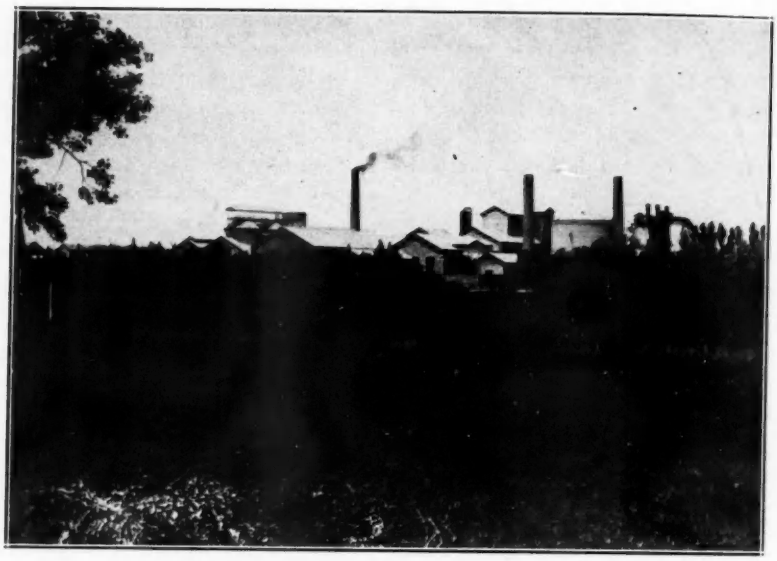


FIG. 9.—Solvay chemical plant, near Salin de Giraud.

The extent to which sea-level has risen in Recent time may be ascertained from various lines of evidence. Knowing something of the area covered by late Wisconsin ice and basing estimates of thickness largely on comparisons with observed conditions in Greenland and Antarctica it is possible to compute the approximate volume of the ice and hence the change in sea-level caused by the evaporation of water which was imprisoned as ice upon continental surfaces. The answers in greatest favor among authorities at present are in the neighborhood of 90 to 100 meters (41). The maximum possible lowering has been calculated as 131 meters. With several uncertain factors in the equation it is natural that estimates vary. Daly has estimated the lowering as being 262 feet (28–725). Antevs summarized many studies along these lines and came to the conclusion that seas were lowered between 290 and 305 feet (1–81). Another approach is based upon measurements of alluvium in drowned valleys. The base of the Flandrienne, or Recent formation of Europe, is at least 72 meters below today's sea level (40–865). This figure is in close agreement with the base of the Recent in central Louisiana. Evidence from continental shelves offers still another solution to the problem. It was suggested almost a century ago that 100 fathoms represents the depth of shore lines during the period of maximum

cold (4–134), rather than wave-base of modern seas. Greater detail in soundings has now established about half that depth as the most typical level for continental shelves, a value in reasonably close agreement with depths of alluvium in coastal valleys. An interesting and fairly precise value in this connection is the estimate that seas must rise from 130 to 200 feet above today's levels if deglaciation continues to completion. Though today's ice-caps seem remote and in many ways inconsequential, our continental outlines, distribution of population, climates, and general conditions hang in a delicate balance, which has swung only a little better than half-way away from Ice Age conditions. To picture broad continental shelves cut at wave-base of seas regulated in level by the extent of ice-caps one must assume wholly improbable rates of erosional planation.

When we visualize the physical results of a contemplated rise of all seas to levels some 200 feet above those of today we are in a proper frame of mind to consider what has taken place along all continental margins during Recent time. We see that such a thing as a shore line of emergence is not likely to characterize any considerable stretch of coast anywhere. We can appreciate the reason why drowned valleys exist along practically all coasts today. In the alluvial deposits of any typical valley a thickening sedimentary section has buried successive floodplain surfaces so that only "modern" channels and topography is now exposed to view.

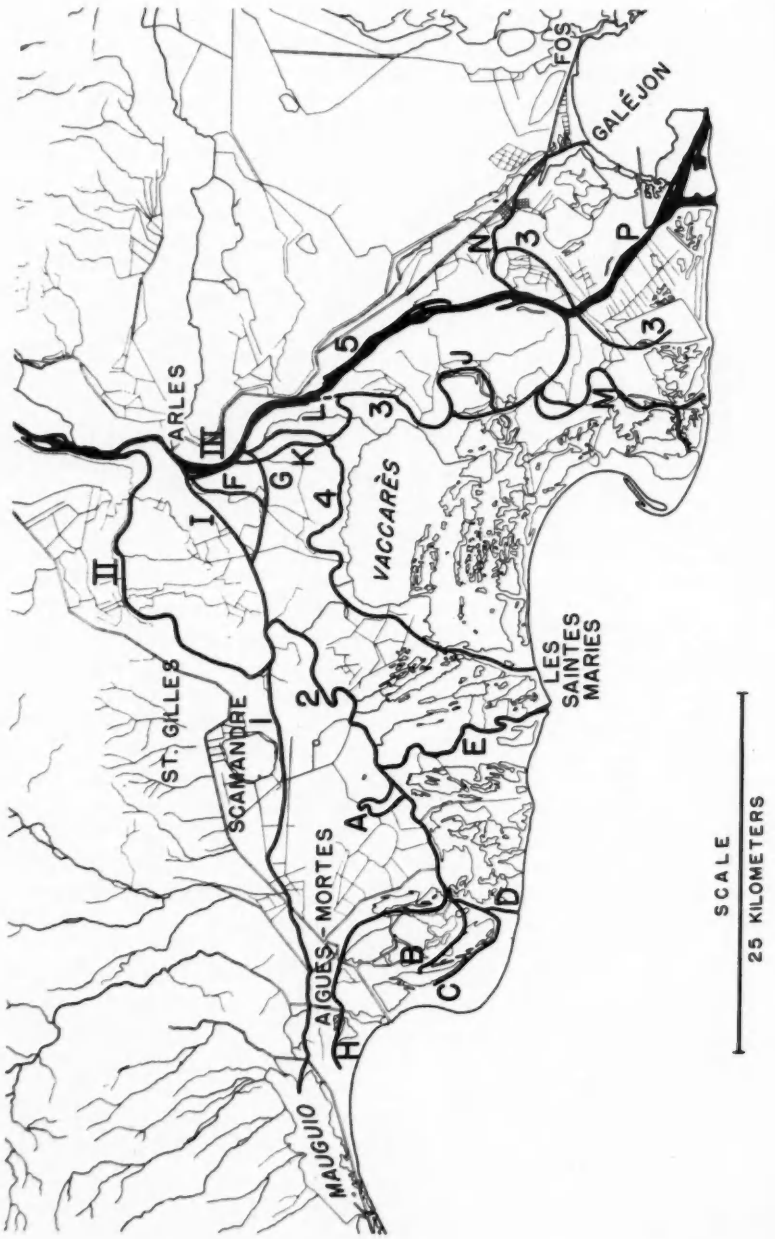
It was during the Recent period of rising seas that the existing Rhône delta was built. The stream channels that contributed the lion's share of its volume are represented by lenticular trains of sand and gravel incorporated in sediments now lying below the level of the Mediterranean. The channels we find today on the delta surface are all "modern." An age of 5,000 years might be excessive for the oldest relict channel in any way indicated at the surface. Archaeologic materials recovered from the delta date back to the 5th or 6th century, B.C. Several important channels have originated since that time, the dates being known exactly in some instances. Other channels are older. Some of the oldest channels are still active but some were abandoned so long ago that rather subtle techniques of coastal plain geomorphology are necessary for their identification.

Channel Sequence

Modern channels of the Rhône delta are indicated in Fig. 10. Individual channel histories are summarized below.

Rhône d'Albaron

Rhône d'Albaron is such an old channel that almost all writers have followed de Beaumont in the belief that its natural levees are ancient beach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25 KILOMETERS

FIG. 10.—Modern channels of the Rhône delta. I = Rhône d'Albaron, II = Petit Rhône (Fourques channel), III = Grand Rhône, 1 = Tourradons channel, 2 = Silvéréal channel, 3 = Rhône d'Ulmet, 4 = Rhône de Saint-Ferreol, 5 = Existing Grand Rhône, A = Abandoned portion of the Silvéréal channel, B = Rhône-mort, C = Rhône de Saint-Roman, D = Rhône-vif, E = Rhône d'Orgon, F = Roubine Triquette channel, G = Gageron channel, H = Rhône-mort aux Tombes, J = Part of Rhône d'Ulmet, K = Roubine de la Grand Montlong channel, L = Possible channel at Beaujeu, M = Bras de Fer, N = Bras Mort, P = Saint Louis channel.

deposits, a view contested only within recent years as the result of the recognition of their true nature by Denizet (33–427). Though it was mentioned in the statutes of Arles in 1151 as an old channel (52–364), many modern authorities still regard it as questionable (51–8). This channel is designated I in Fig. 10. Described in terms of today's geography, it left the vicinity of Arles and the course of the Grand Rhône with flow directed southwestward across the Camargue to the Little Rhône at Albaron.

The original channel is obscure for most of this distance, the most reliable guide as to its position being strips of light colored, spongy ground along the central part of a continuous ridge of high, sandy land. The sandy natural levees now exhibit a minimum width of one kilometer and widen to three kilometers toward Île de la Cappe. Their dryness and firmness have localized vineyards along the old Rhône course and are responsible for the routes taken by both railroad and main highway between Arles and Saintes-Maries. In striking contrast lie the low, wet Marais du Pont de Rousty, to the north, and Marais de la Grand Mar, to the south. The natural levee ridge exhibits the relatively straight pattern of a major stream, possibly the whole Rhône of the day, the bends being few and having long radii of curvature.

Tourradons Channel

Tourradons channel (Fig. 10; 1) continues the Rhône d'Albaron course westward from Mas de la Fosse, on the Petit Rhône, past Mas des Iscles and Pont des Tourradons, into the low territory east of Étang de Mauguio (Figs. 11, 12). Though parts of the original channel have been adopted by other streams or have been canalized, the Tourradons course is most positively followed on the basis of natural levees. These are continuous with and duplicate pattern characteristics of those of the Albaron channel. Levee crests slope westward and as they approach the level of adjacent marshes there is a notable decrease in the width of relatively dry and useful land. A road runs along one of the crests as far as Mas des Iscles. Beyond Pont des Tourradons the levee crests reach marsh level. Still farther west, toward Pointe du Radel, the crests are covered by subsequent alluvial cones of the Vidourle, Vistre, and other streams.

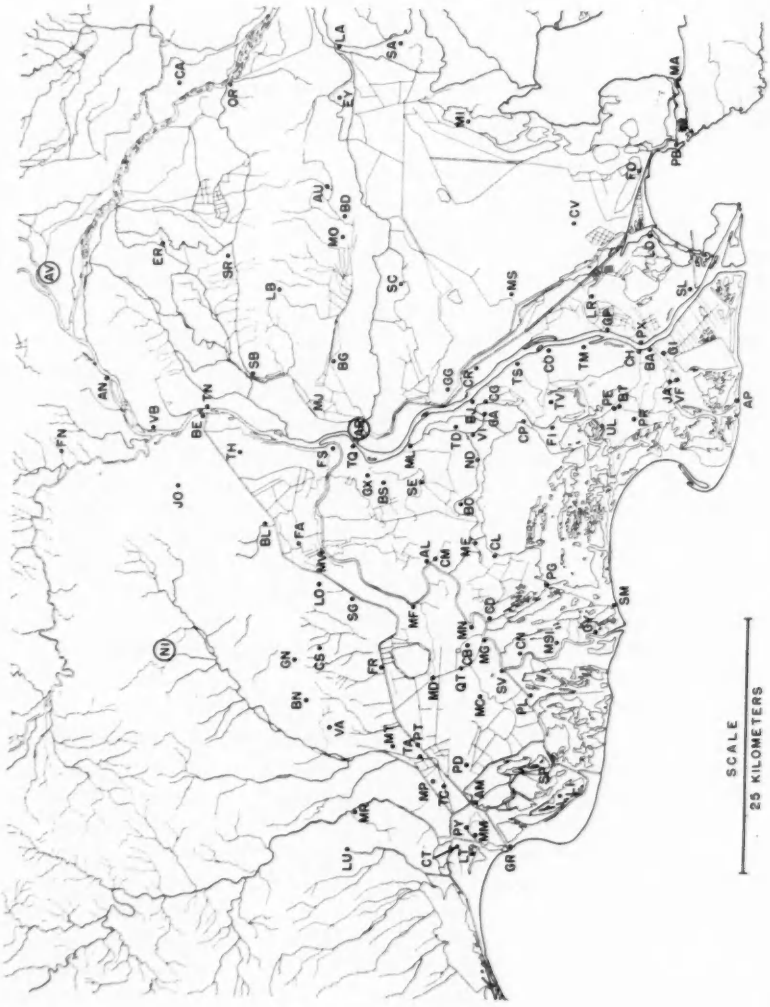
SCALE
25 KILOMETERS

FIG. 11.—Index map, cultural features of the Rhône delta region. AL = Albaron, AM = Aigues-Mortes, AN = Aramon, AP = Ancien Phare de Faraman, AR = Arles, AU = Aurielle, AV = Avignon, BA = Barcarin, BD = Château de Beauregard, BE = Beaucaire, BG = Château de Grand Barbegal, BJ = Beaujeu, BL = Bellegarde, BN = Beauvoisin, BO = Bourgogne, BS = Bastières, BT = St. Bertrand, CA = Cavaillon, CB = Cabines de Pêcheurs, CD = Château Davignon, CG = la Chassagnette, CH = Chamone, CL = Carrelet, CM = Combet, CN = Château d'Astonin, CO = la Commanderie, CP = la Capellière, CR = Champtercier, CS = Château de Surville, CT = Chaumont, CV = Cabane du Ventillon, ER = Eyragues, EY = Eyguières, FA = Mas de Fangues, FI = Fièlouse, FO = Fos, FN = Fournes, FR = Franquevaux, FS = Fourques, GA = Gageron, GG = Grand Galignan, GI = Giraud, GN = Génerac, GP = Grand Passon, GR = Grau du Roi, GX = Gimeaux, GY = Mas Gelly, JA = Mas du Japon, JO = Jonquières, LA = Lamanon, LB = les Baux, LD = la Roque Dour, LI = Château du Listel, LO = Mas de Loubes, LR = le Radeau, LT = les Tombes, LU = Lunel, MA = Martigues, MC = Montcalm, MD = Mas des Iscles, ME = Méjeanne, MF = Mas de la Fosse, MG = Mons. des Gardes, MI = Miramas, MJ = Montmajour, ML = Montlong, MM = Mas du Môle, MN = Mas neuf de Capettes, MO = Mouries, MP = Mas de Psalmody, MR = Marsillargues, MS = Mas d'Icard (Crau), MSI = Mas d'Icard (Orgon), MT = Mas Melet, MV = Mas du Village, ND = Notre Dame d'Amour, NI = Nimes, OR = Orgon, PB = Port de Bouc, PD = Pinède, PE = Pont des écluses, PG = Pont des Cinq Gorges, PL = Poste de la Larbière, PR = la Pebre, PT = Pont des Tourradons, PX = Grand Peloux, PY = Mas du Peyret, QT = Quattret, SA = Salon, SB = St. Gabriel, SC = St. Martin-de Crau, SE = Sainte-Cécile, SG = St. Gilles, SL = Port St. Louis, SM = les Saintes-Maries, SP = Salins de Peccais, SR = St. Remy, SV = Silvéréal, TA = Tour d'Anglas, TC = Tour Carbonnière, TD = Tour de Montmeillan, TH = Thieuloy, TM = Tour de Manusclat, TN = Tarascon, TQ = Trinquetaille, TS = Tour de Caseau, TV = Tour du Valat, UL = Ruines de l'Abbaye d'Ulmet, VA = Vauvert, VB = Vallabrègues, VF = Ancienne Vigie de Faraman, VI = Villeneuve.

Natural levee patterns are clear in demonstrating the original continuity of the Albaron-Tourradons channel. The only complications associated with its recognition exist at its head, where three pairs of natural levees lead into the Albaron channel. Those old channels may be called Bastières (I in figure 10), Roubine Triquette (F), and Gageron (G). Two of the courses, Bastières and Gageron, exhibit particularly impressive levee systems and hence appear to have functioned for a longer time than the other. Though Roubine Triquette has the least well developed levees it exhibits the freshest channel and hence appears youngest. A rational explanation of the interesting problem of channel sequence at the head of the Rhône d'Albaron demands the recognition of Gageron as the original course. Its leeves originally extended upstream, more or less along the route of the existing Grand Rhône in the vicinity of Arles. About six or seven kilometers below Arles the channel made a sweeping bend toward the west and continued across what is now the High Camargue and into the Tourradons course.

After the Gageron head of the Rhône d'Albaron had built natural levees

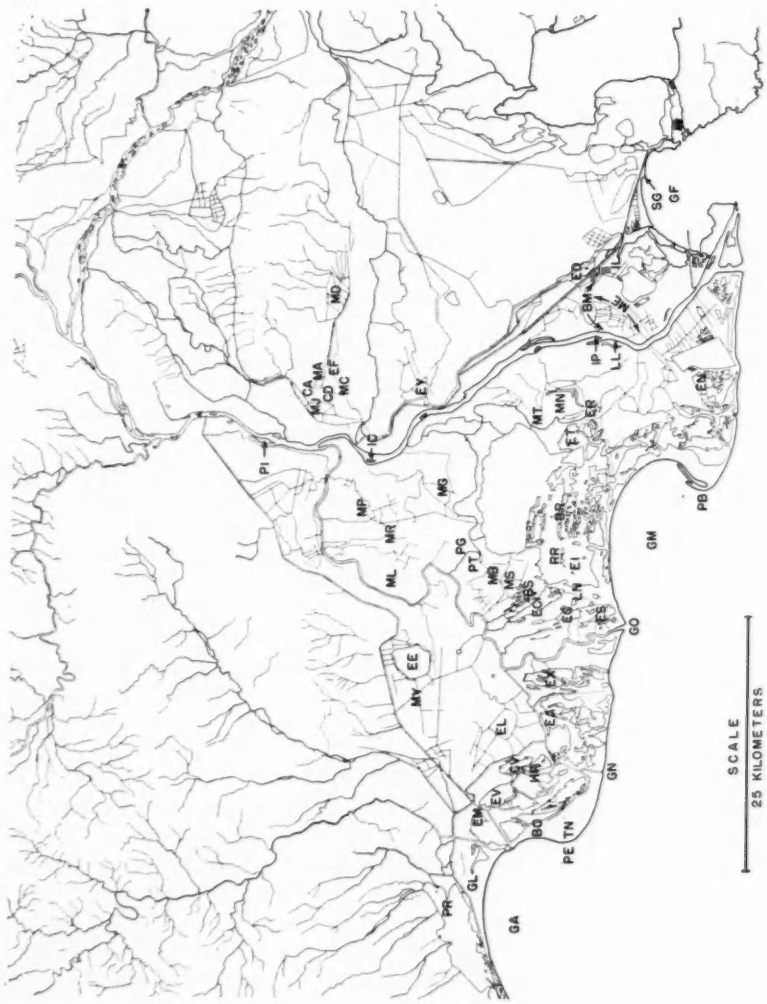
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FIG. 12.—Index map, natural features of the Rhône delta region. BM = Bras Mort, BO = Boucanet, BR = Bois des Rièges, BS = Baisses de Saxi, CA = le Castelet, CD = Mont de Cordes, CV = Étang de Caïtives, EA = Étang de l'Arameau, EC = Étang de Consécanière, ED = Étang du Landres, EE = Étang de Scamandre, EF = Étang de Figuerolle, EG = Étang de Ginès, EI = Étang dit l'Impérial, EL = Étang de Lairan (Grand Palus), EM = Étang de la Marette, EN = Étang de Faraman, ER = Étang Redon, ES = Étang des Launes, ET = Étang du Fournelet, EV = Étang de la Ville, EX = Étang des Fourneaux, EY = Étang de Meyranne, GA = Golfe des Aigues-Mortes, GF = Golfe de Fos, GL = Gué du Port Louis, GM = Golfe des Saintes-Maries, GN = Grau neuf, GO = Grau d'Orgon, HP = Herbage du Petit Peccais, IC = Île de la Cappe, IL = Île de Lansac, IP = Île des Pilotes, LL = la Louisiane, LN = le Levadon, MA = Mont d'Argent, MB = Marais des Bruns, MC = Marais du Grand Clar, MD = Marais desséchés des Baux, ME = Marais de l'Escale, MG = Marais du Grand Mar, MJ = Montmajour, ML = Marais de Saliers, MN = Marais de St. Seren, MP = Marais de Palun longue, MR = Marais du Pont de Rousty, MS = Marais de la Sigoulette, MT = Marais de Grenouillet, MY = Marais du Crey, PB = Pointe de Beauduc, PE = Pointe de l'Espiguette, PG = Pâtis de Gouyère, PI = Île Pilet, PT = Pâtis de la Trinité, RR = Radeau Redouière, SG = Anse de St. Gervais, TN = Terre Neuve.

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of considerable size, a crevasse on the right bank, near the existing Île de la Cappe, established the Bastières channel, some five kilometers upstream from the Gageron bend. After following the southward slope of the land for a short distance the new channel was blocked, near Bourgogne, by the old right bank levee of the Gageron course. The escape of waters was accomplished by breaking through this levee and flowing down the Albaron channel. The Bastières channel, once established, had the advantage of shortness, so it prospered and functioned for a long period, during which it built an impressive set of natural levees.

Roubine Triquette originated much later than the channels just described, even subsequent to some of the channels to be considered later in this report. Its head was a crevasse near Île de la Cappe, a short distance downstream from the head of the Bastières course. Water flowing through this crevasse was trapped on all sides by natural levee ridges. To escape it had to pond, rise, and overtop the lowest downstream barrier. This place was on the right band levee of the old Gageron channel and it led waters into the Albaron course.

Though Roubine Triquette is the freshest channel leading into Rhône d'Albaron, the course most evident in the field and the one best shown on detailed maps, it was always a relatively unimportant stream and it probably contributed little or nothing to the sediments of Rhône d'Albaron levees. The meander pattern of Roubine Triquette is characterized by bends much smaller and sharper than those of the Albaron-Tourradons channel, the existing Grand and Petit Rhônes, or any other main channel in the delta.

This pattern must be associated with relatively small discharge. It is well developed, a fact indicative of use during a relatively long period, during which the bends were sufficiently accentuated to become nicely developed meanders. The main discharge of the Rhône obviously was directed along other channels when Roubine Triquette was in its prime.

Rhône of Beaucaire

Gerin-Ricard (52–365) described as the Rhône of Beaucaire a hypothetical channel extending from the existing Grand Rhône about 11 kilometers north of Fourques to the vicinity of Sète, to the west of the region shown in Fig. 10. He visualized it as very old and believed that it determined much of the route of the existing Canal du Rhône à Sète. This is one of many suggestions that a channel once extended from the head of the delta to the extreme western part of the deltaic plain. The necessity for recognition of a channel leading in this direction has been felt for several reasons, historical, petrological, and geomorphological.

Nothing in today's topography justifies the recognition of a Rhône of Beaucaire. The complete absence of natural levees is a fatal blow to the entire concept. It cannot be emphasized too strongly that in floodplain studies old channels are indicated by the presence of their deposits, their absence by the presence of lowlands. The proposed Rhône of Beaucaire was located entirely in the normal lowland between the backslopes of various natural levees and the alluvial apron or wall of the valley side. Only minor, "rim swamp" (107–1224), streams occupy this position in any flood plain.

The absence of a Rhône of Beaucaire during modern times does not militate against the location of the Rhône at the foot of its western valley wall at some earlier time during the Recent epoch. The escarpment between Beaucaire and St. Gilles exhibits several conspicuous meander scars of a pattern suggesting that they were cut by the whole Rhône, or at least a major distributary. An excellent example occurs about five kilometers below Bellegarde. The arcuate cut is a gentle bend having a radius of curvature almost identical with that of the Petit Rhône on either side of Mas du Village (Fig. 12). The channel responsible for these scars flowed at a level considerably lower than today's flood plain and its natural levees have been entirely covered by modern alluvial, "back swamp" deposits. A line of bore-holes from Bellegarde to the Grand Rhône would readily establish the size and position of this old channel. Below St. Gilles there is no evidence whatever of any old Rhône channel north of the Tourradons course.

Stagna of St. Gilles

Consideration of a possible western Rhône channel leads us into an inter-

esting historical problem, the identification of a route used by navigators during the Middle Ages, which may be called "Stagna," or, specifically, "Stagna of St. Gilles."

The earliest rather complete topographical description of the Rhône delta, the Peutinger Table of the 3d or 4th century, B.C., indicates three branches of the Rhône below Arles but it omits mention of étangs, salines, or other features that might be helpful in identifying them, a serious matter because it also lacks scale or proportion (90–404). Strabo (114: 4.1.8) reviews the number of Rhône mouths according to various classical writers. The Portolan Charts of the 13th, 14th, and 15th centuries represent the Rhône delta in a conventional and inaccurate manner, differences between individual charts arising in varying degrees of skill in drafting rather than in additional information in the later copies. The Barentzoon map of 1593 (Fig. 13) is a glorified attempt to summarize Portolan information.

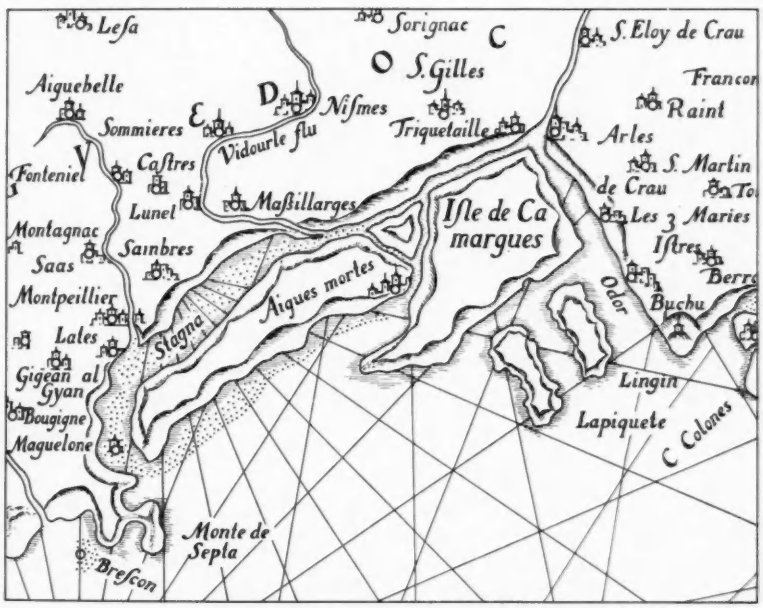

FIG. 13.—Barentzoon Map of 1593.

Monte de Septa (Sète) is shown at the mouth of Stagna, an inland sea extending from the Island of Maguelone (Maguelonne) to the vicinity of Arles. Montpellier is near the mouth of the Lez and Masillarges (Marsil-

largues) is properly shown on the Vidourle. On the first really new map of the delta since the construction of the first Portolan, the Jean Bompar map of 1594 (Fig. 14), all main channels of the Rhône are shown east of Aigues-Mortes, so that Stagna, or the hypothetical Rhône of Beaucaire,

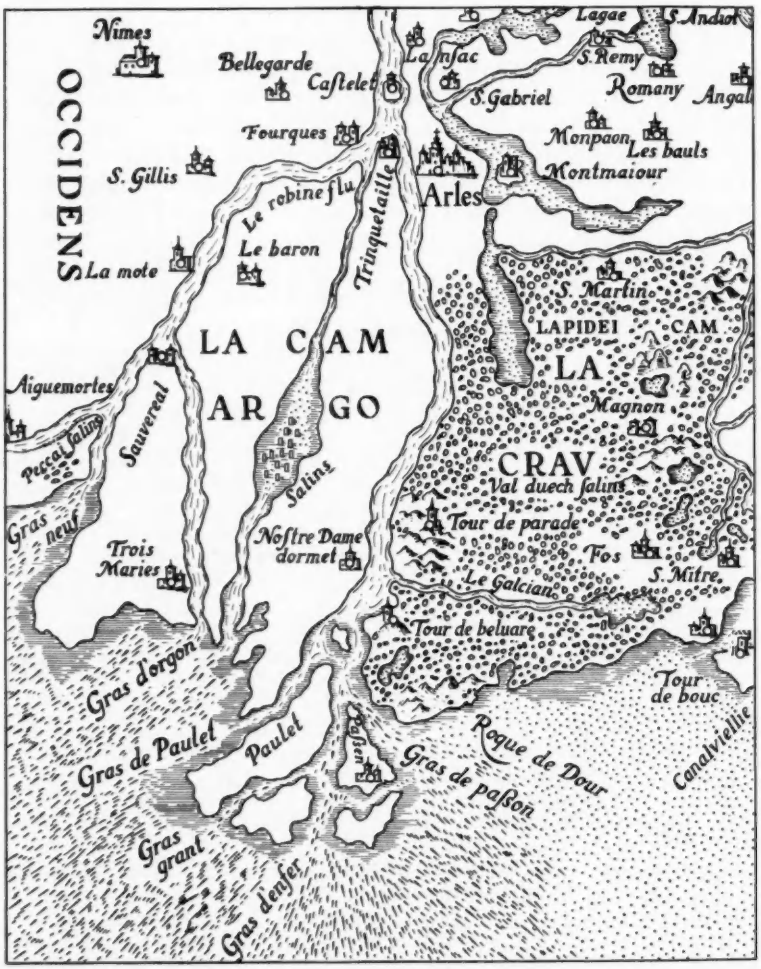

FIG. 14.—Jean Bompar Map of 1594.

had ceased to be considered as a river channel by that date. In most Portolan representations Stagna, *Stagnom*, or *Stagnum aquæ mortuæ* appeared broad and marshy, rather than as a distinct and active Rhône distributary.

That Maguelonne was once an island is well established. The Saracens held it as an important port. Charles Martel expelled them and centuries later the town became a Protestant stronghold until destroyed by Louis XIII (98–113). Little is there now except the ruin of an ancient church in the midst of sands of an offshore bar that extends, with but slight interruption, from Cap d'Agde to the vicinity of Grau du Roi, near Aigues-Mortes. The maps of Gaspard Viegas, 1583, and of Bartholomé Olivès (de Majorque), 1584, show the Petit Rhône extending to and around the Île de Maguelonne, Stagna being the channel. Festus Avienus, at the end of the 6th century, described the mouth of the Spanish Rhône as lying even farther west, in the vicinity of Mons Setius (Sète). This idea is contained in many Portolans, some showing the Petit Rhône as extending into Étang de Thau (79–50). In some of them the channel appears navigable and confined, in others it is broad and shoal, containing islands (90–405).

In addition to cartographic arguments in favor of a modern western Rhône are certain historical facts and arguments that might appear conclusive on first blush. Most of these are related to St. Gilles and are attempts to justify statements to the effect that it was once one of the greatest ports of France.

Though St. Gilles is now some 25 kilometers inland and 1.5 kilometers from the Petit Rhône it was ordinarily considered as the principal port of departure for pilgrims to Palestine in the 12th century (98–103), the most important port on the southern coast of France during the 11th and 12th centuries (90–413), or at least a very busy port during the 12th century (97–121). Numerous references appear to bear out such statements. In 1086 Emma, daughter of the Count of Sicily, landed there on her way to the Court of France. In 1109 Bertrand, Count of Toulouse and St. Gilles, collected a fleet of 40 ships at St. Gilles for the transportation of 4,000 knights to the Holy Land. Interesting encounters between Pisan and Genoese galleys involved several trips along Stagna between some pass near Maguelonne and Arles (90–414). The channel was shoal and blocked the larger Genoese boats. Even the smaller craft of the Pisans were stranded below St. Gilles on one occasion. This was in 1165.

The true attraction of St. Gilles appears to have been spiritual rather than material. According to Callender, warships were particularly desirous of visiting the town in order to receive blessings (90–425). The first overseas establishment of the Knights Hospitaler of St. John was founded at St. Gilles in 1112 because the place had the reputation of being the chief

port for the embarkation of pilgrims. Yet St. Gilles was in no sense a good seaport for even the shallow draft ships of the 11th or 12th centuries. No Portolan chart shows it. Toulon and Fos were in reality the principal deep water ports of southern France and St. Gilles was an inland point with only an extremely poor connection to the sea in its vicinity. When its spiritual significance was replaced by that of nearby Aigues-Mortes the decline of St. Gilles was precipitous. The vicissitudes of later religious wars caused further decay and even its chief glory, the church, which was fortified by the Huguenots in 1562, was nearly demolished in 1622. The beautiful western front of this edifice, with the carved lions after which the Golfe du Lion is named, fortunately escaped with rather minor mutilation.

The decline of St. Gilles as a seaport is in no sense proof that the Rhône delta has advanced notably since the 12th century, as many have supposed. Advocates of this notion cite such facts as the description by Rabbi Benjamin of Tudela, who visited St. Gilles in about 1160 and described it as being on the bank of the Rhône about three miles from the sea. The "sea" in this description was certainly not the Mediterranean, but was the eastern end of Stagna and, specifically, the shallow body of water now called Êtang de Scamandre (90–414), Fig. 12, "EE."

While the decline of St. Gilles has been attributed to the decline of Stagna as a result of silting, the true facts appear to be exactly the reverse. Stagna declined as a route for the reason that St. Gilles lost its spiritual attraction to Aigues-Mortes and its commercial attraction, a fair that brought people from many distant lands, to Beaucaire in 1217, on order of Raymond VI of Toulouse. Disuse favored silting.

In 1226 the Treaty of Paris transferred authority over the southern coast of France from the Counts of Toulouse to King Louis IX of France. In 1248 Louis purchased, at the nearby Abbaye de Psalmodi, land necessary for the founding of his own Mediterranean seaport, Aigues-Mortes. At great expense he constructed a road across the marshes and bridged Stagna. Both Stagna and the road were commanded by an advance fortification, Tour Carbonnière, which still stands as a lonely sentinel. The town itself was built on the natural levee of an old Rhône channel rather than upon the immediate sea coast. It enjoyed many subsidies, which in part made up for the fact that it was not located on deep water, as many have supposed (90–419).

Aigues-Mortes served as the port for the first Crusade under the leadership of St. Louis, in 1248, and also for his ill-fated second Crusade of 1270 (99–77). Magnificent ramparts, built during the reign of Philippe le Hardi, in 1272, are today in excellent condition. After replacing St. Gilles spiritually Aigues-Mortes rose commercially and for a short time served

as the port for Nîmes and most of Languedoc. Glory based upon the whims of rulers, however, is likely to be short lived. Aigues-Mortes declined sharply after 1490, when Toulon was granted equal subsidies. The crushing blow came later, when Richelieu developed Toulon as the base for the French navy. Today Aigues-Mortes, though well kept, is essentially a beautiful but deserted monument (Fig. 15).

FIG. 15.—Across Aigues-Mortes from the rampart, toward Étang de la Ville.

Geological advocates of a modern western Rhône have much to say about the occurrence of rare types of rock on the beaches west of Aigues-Mortes. Most of these rocks resemble types known only in the basin of the Durance (79–50; 86). The finds are concentrated along Mediterranean shores south of the existing étangs of Pérols and Mauguio. Palavas, near Mauguelonne, is ordinarily regarded as the western boundary for these materials (16–201) but Charles Martins, the most eloquent advocate of the theory, says they extend as far as Sète, where he pictures the old Rhône mouth (79–46). The pebbles under discussion might conceivably have come down the Tourradons channel but certainly could not have made their way along the shallow lakes and channels of Stagna. In all probability they were actually carried by streams of an earlier date than any which have left

LE LITTORAL MEDITERRANEEN PRÈS D'AIGUESMORTES

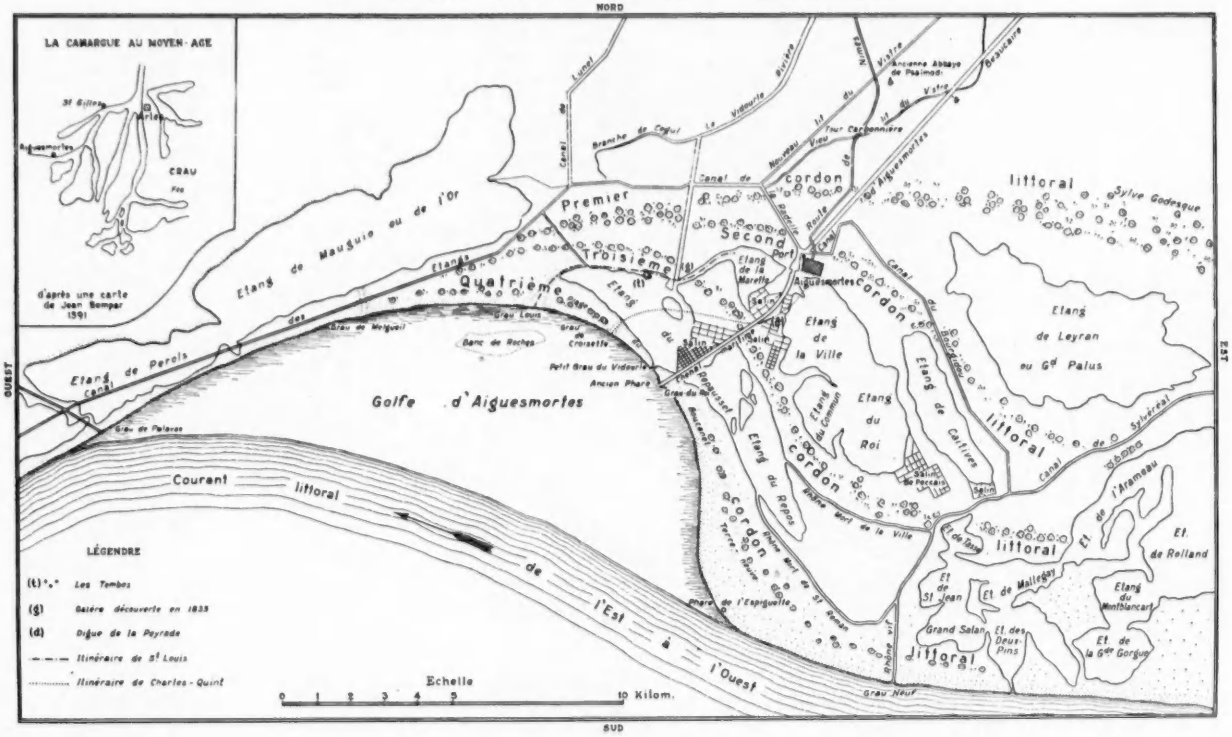

FIG. 16.—Aigues-Mortes and vicinity (After Charles Martins).

scars on today's surface. Their concentration along old and modern beaches has been the product of wave action.

It is apparent that Stagna was never a true river channel. It was nothing more than a marshy tract with shallow lakes and winding channels through which small boats, with difficulty, could make their way up to the vicinity of St. Gilles and, under favorable conditions, into the Petit Rhône.

Various inlets of étangs de Thau, d'Ingril, de Vic, de l'Arnel, de Pérols, and de Mauguio served as connections between Stagna and the Mediterranean. These have always been more or less confused in the minds of writers with actual mouths of the Rhône. Most of them were near Maguelonne, though some were as far west as Sète. The easternmost inlet seems to have been Grau de Melgueil, near the eastern end of Étang de Mauguio (Fig. 16). It was used by the Pisan fleet in 1165 and it had existed in ancient times as well, when it was known as Gradus Mercuri. It may have been the Spanish Branch of the Rhône, as recognized in the 1st century, B.C. (99–58). In any event this branch was near Étang de Mauguio and was almost certainly an inlet to Stagna rather than actual river mouth.

Gradus Capræ, often mentioned as the western mouth of the Rhône between the 11th and 13th centuries, was nothing more than the end of a short channel leading from the Petit Rhône near St. Gilles to Étang de Scamandre. It was emphasized in literature because of difficulties with shoals where boats crossed from narrow channels to the first of the relatively broad lakes in the Stagna depression.

There are really two types of étangs along Stagna. The western étangs are coastal lagoons behind the offshore bars along the Mediterranean (31–280). A good example is de Mauguio. Sheltered waters of such lagoons are always sought by shallow draft boats, such as were used in Antiquity and the Middle Ages. In the United States today they have been utilized extensively by the Intracoastal Canal along the coasts of Southeastern and Southern states. The very presence of such lagoons is positive proof that no significant Rhône channel led to them. Had such been the case they long since would have been filled with sediment. Stagna east of de Mauguio contained the typical shallow lakes of coastal marshes.

Though Stagna was not a river channel it came into being as a result of the Tourradons channel, whose natural levees blocked drainage from the flood plain west of the Rhône below Beaucaire and the southern slopes of the Costière, concentrating flow westward, toward the lagoons. The wetness of the marsh north of the Tourradons levees has been accentuated by subsidence due both to the gradual sinking of the whole delta and to localized settling conditioned by the weight of the natural levees themselves.

As long as Stagna was used as a route for navigation passing boats and such maintenance as was necessary kept the channel open but when once abandoned alluviation from the Vistre and other streams hastened its decline. The broad alluvial cone of the Vidourle probably narrowed Stagna considerably during its most useful days. It has now practically covered parts of the lowland and has forced the Vistre into the old Tourradons channel. Less change has occurred toward the east. Marshes have developed at the expense of étangs and channels have deteriorated, but the residual Étang de Scamandre is still five feet deep.

Oldham (90–413; 419) regards subsidence during the Middle Ages as responsible for Stagna. The Abbey of Psalmodi was an island in this marshy sea. Even today it is surrounded by wet marsh and the territory to the south is deeply saturated most of the time. To the writer it seems improbable that any pronounced subsidence preceded the Middle Ages nautical activities along Stagna. The natural levees of the Tourradons channel and the sandy cheniers near Aigues-Mortes are all older than Stagna and their surfaces indicate freedom from submergence beyond that existing now. The presence of Tourradons levees in the low marshy coastal plain is a sufficient reason for Stagna.

Subsidence, at the slow rate apparently going on at present, is favorable for the preservation of Stagna. Alluviation always threatened its existence. In the contest between subsidence and alluviation the former probably was more favored during the Middle Ages than at present. An examination of the channel patterns of the Vidourle and Vistre suggests that both of these streams formerly discharged farther to the west than they do today, contributing to the large but now somewhat abandoned alluvial cones south of Lunel. When their courses changed so that their activities were directed toward Aigues-Mortes the result was unfavorable for the perpetuation of Stagna. It is also possible that increasing agricultural use of land so stimulated the rate of erosion and sedimentation that a balance has swung from a slight advantage on the side of subsidence to one on the side of deposition and filling of Stagna.

The occurrence of alpine schists, euphotides, variolites from Mont Genèvre, and rocks of probable Durancian origin on the beaches west of Aigues-Mortes (79–46), in reality has nothing to do with the Stagna question. They confirm the fact that Rhône channels have wandered over a broad deltaic plain, extending from Sète to Fos, but to assume that this has been the case in geologically modern times is to contradict all major facts of the delta topography as it exists today.

Petit Rhône (Fourques Channel)

Petit Rhône (Fourques channel) is indicated in Fig. 10 as "II." This is the existing Petit Rhône between its bifurcation from the Grand Rhône and Mas de la Fosse (Fig. 11). It is clearly of recent origin, the natural levees being high and bearing soils by no means as far advanced toward profile maturity as those along the Albaron channel. The pattern of the Fourques channel is also immature. Each bend has an obvious origin and meandering tendencies have barely started anywhere. Individual bends are sharp and are widely spaced.

The Fourques channel originated from a right bank crevasse some three kilometers above Arles. The original flow was almost due west, down the natural levee of the Grand Rhône. At the point of bifurcation meandering tendencies have converted the original channel head into a smooth, sweeping curve. Several slight bends along the westward segment of the upper channel indicate the initiation of meandering. Near Mas du Village (Fig. 12) the stream encounters the foot of the alluvial apron along the hills north of St. Gilles and is forced to turn southward. Low alluvial cones near Mas de Loubes force the channel into a striking bend just to the east of St. Gilles. Farther downstream the channel is comparatively straight until it reaches Mas de la Fosse. Here it encountered the right natural levee of the Tourradons Rhône, which it breached so that it entered the channel.

Between Mas de la Fosse and Albaron the Petit Rhône follows the Tourradons channel but reverses the original direction of flow. Such behavior is commonplace in the evolution of hydrographic patterns in the lower Mississippi Valley and presumably elsewhere.

Silvéréal Channel

Silvéréal channel (Fig. 10, "2") includes the existing Petit Rhône below Albaron and several variants which are now abandoned.

The contrast in pattern between Fourques and Silvéréal channels is both striking and significant. The latter is by all odds the more sinuous and the bends are those of meanders in a relatively advanced stage of development. They are not widely spaced along the channel, as in the former case. The Silvéréal channel is thus shown to be the older on the basis of pattern.

The reversal in direction of flow between Mas de la Fosse and Albaron is an additional proof that the Silvéréal channel is older than the Fourques. It originated from the old Albaron-Tourradons course as the result of a crevasse at Albaron. The creation of the Silvéréal channel was the result

of non-piratical beheading of Tourradons and was the first important step in its ultimate decline. Shorter distance to the Mediterranean favored the Silvéréal course. Complications resulting from the shifting heads of Rhône d'Albaron probably affected discharge volumes downstream but the patterns of meanders along Silvéréal suggests a discharge not radically different from that of Rhône d'Albaron when it led into the Tourradons channel.

It is possible that all of the Albaron heads had been sealed off before the Fourques channel was created. In any event the Silvéréal outlet was more attractive than Tourradons when flow down the Fourques channel breached the levee at Mas de la Fosse. This suggests that the Tourradons channel had suffered much deterioration at the time. The very name "Mas de la Fosse," however, suggests critical weakness in the right bank levee of the Petit Rhône at the place where it is built up across the Tourradons channel, within comparatively recent times. Historical facts bear out the statement as will be shown later.

The main variants in the Silvéréal channel are designated "A," "B," "C," "D," "E," and "H" in Fig. 10. Others might have been added but they are of less consequence, being more in the nature of crevasse channels than of significant distributaries. Though these smaller streams have left important alluvial deposits in several cases they all succeeded in sealing themselves off eventually. Most crevasse deposits are located along the left bank of the Silvéréal course.

The peculiar sharp bend "A" is followed by the boundary between the Departments of Gard and Bouches-du-Rhône and thus appears to have been part of the active Silvéréal channel when this boundary was defined. Its origin will be considered later.

Rhône-mort

Rhône-mort ("B" in Fig. 10) also bears the name Rhône-mort de la Ville. Though prehistoric (99–67), it carried enough water to flood the salines of Peccais until detoured on the order of François I, in 1532 (16–203), and in all probability contributed to the flooding of Aigues-Mortes when the artificial levee of the Petit Rhône failed near Mas de las Fosse on Nov. 4, 1840 (79–49).

Rhône de Saint-Roman

Rhône de Saint-Roman ("C" in Fig. 10) parallels Rhône-mort on the southwest. It was the most active true western channel of the Rhône in ancient times. Near its outlet, Grau de la Chèvre, was an important Greek and Roman settlement (14–25; 52–364). This pass, or grau, was located

close to the existing artificial Grau du Roi, southwest of Aigues-Mortes, and probably has the best claim of any Rhône outlet to recognition as the mouth of the Spanish Rhône, l'ostium hispanienne, as described by d'Artémidore and Pliny (52–365).

Rhône-vif

Rhône-vif ("D" in Fig. 10) leads to Grau neuf. These names are suggestive of recency and refer to the artificial cutting of the channel in 1532 by François (79–57). There is some possibility that the channel was essentially natural and that protection of Salines de Peccais was accomplished by improvement rather than the creation of an entirely new outlet. Oldham (90–416) believes that Grau neuf was the principal mouth of the Petit Rhône during the 13th and 14th centuries. If he is correct, François instigated a less radical change than he is usually given credit for.

Rhône-mort aux Tombes

Rhône-mort aux Tombes ("H" in Fig. 10) is a name here suggested for a channel not previously recognized as far as the writer is aware.

Most Portolan charts, the Barentzoon map (Fig. 13), and the Jean Bompar map (Fig. 14) agree in showing Aigues-Mortes on the right bank of a channel. Field examination shows this to be true, but the channel has deteriorated badly along much of its course. The case is clearest west of town. In Fig. 16, a map constructed primarily to show the route of St. Louis between Aigues-Mortes and his point of embarkation on the Mediterranean, a relict channel will be noted between Étang de la Marette and Grau Louis. The natural levees of this channel are relatively high and firm today. Mas du Peyret, Mas du Môle, and several other establishments are located on them, as well as les Tombes, the burial ground used during the Crusades. The end of the channel today is known as Gué du Port Louis, but all traces of the actual mouth at the time of Louis have been lost as the result of shore accretion and burial by dunes. Aigues-Mortes is located on the firm, right bank natural levee of this same channel. To the southeast the channel itself has deteriorated almost beyond recognition at many places but its levees still form a ridge of relatively dry land extending between Étang de la Ville and Étang de Caïtivies. Farther upstream, toward Aigues-Mortes, it is called Herbage du Petit Peccais and the channel has been in part canalized. This is Rhône-mort aux Tombes, one of the early distributaries of the Silvéréal channel. In pattern it closely resembles Rhône-mort and Rhône de Saint-Roman.

Northwestward Distributaries

The trends of Silvéréal distributaries have been determined by old

cheniers, or marsh bars. On first inspection it might appear that as the coast advanced, new cheniers formed as a consequence, and the channels originated in progressive sequence toward the coast. While the general outlines of this simple hypothesis are true, field evidence shows that the origin of each new northwestward channel did not immediately follow the creation of a new chenier with the same trend. Rhône-mort aux Tombes appears to be one of the oldest northwestward channels and yet it is younger than the next-to-last, or possibly even the last chenier. In Fig. 16 it will be noted that this channel cuts across these cheniers indicating their presence before the channel adopted the course shown. On the map the latest cheniers are indicated as "Troisième" and "Quatrième cordon littoral." The crossings of the next-to-last chenier occurs not far west of Étang de la Marette. As will be shown later, the cheniers were not formed on a regularly advancing coast. Each chenier represents a period of coastal retreat followed by a period of coastal advance. By the time the Silvéréal channel was created all of the cheniers seem to have been present in the region. They acted only as barriers causing first one distributary, then the next, to flow northwestward along the lowlands between them. As the cheniers are roughly parallel in the Aigues-Mortes region, the distributary streams between them are also roughly parallel.

It is likely that the most inland of the northwestward distributaries of the Silvéréal channel was the first to form and that channels closer to the coast are progressively younger. The innermost ridge, Chenier Godesque of this report or the "Premier cordon littoral" of Fig. 16, was a barrier sufficiently developed along its entire length to prevent the Tourradons channel from reaching the Mediterranean. The Silvéréal channel cut through this barrier toward the east where it is comparatively low, as the result of tilting toward an area which is subsiding; the central Camargue.

After crossing Chenier Godesque the earliest Silvéréal channel appears to have flowed northwestward along the depression now called Grand Palus, with its Étang de Lairan. Alluviation, especially toward the west, has covered most of this course and blanketed its details. The anomalous channel "A" of Fig. 10, a local "Rhône-mort," is the residual trace today of this old Silvéréal distributary. Canal de Silvéréal is an artificial cut-off which his diverted the existing drainage down the Silvéréal channel from the old bends followed by the Departmental boundary, saving about eight kilometers in channel distance.

Rhône-mort aux Tombes is the next northwestward channel toward the coast and is presumably next younger in age. It followed the southern side of the "Second cordon littoral" of Fig. 16. Alluviation near Aigues-Mortes by such streams as the Vistre and Vidourle appears to have blocked

the western end of the low valley between Chenier Godesque and the Second cordon littoral, or second chenier, and thus has been responsible for the forcing of the Silvéréal channel from its Grand Palus route to Rhône-mort aux Tombes. In a similar manner the Silvéréal channel was later forced to adopt its Rhône-mort course immediately south of the third chenier and Rhône de Saint-Roman immediately north of the fourth chenier. Though all of these channels are now abandoned and have suffered considerable filling and erasure, they are distinct for the distances shown in Fig. 10. Fig. 17 shows part of Rhône de Saint-Roman. Though it was

FIG. 17.—Rhône de Saint-Roman, an abandoned Silvéréal distributary, about seven kilometers south of Aigues-Mortes.

once an important channel it no longer carries through-flowing waters and is silting-up as a consequence.

Rhône d'Orgon

Rhône d'Orgon, "E" in Fig. 10, is today's lower Silvéréal channel. Les Saintes-Maries, the principal town of the Camargue and only settlement on the shore of the Rhône delta, was originally located on another branch of the Rhône entirely. Its branch deteriorated and was finally cut off arti-

ficially in 1430, leaving the town without a nearby Rhône channel. For this reason the inhabitants, in 1552, dug a canal from the vicinity of the town to the Silvéréal channel and formed Grau d'Orgon (52–364). The canal diverted the Petit Rhône and isolated the Petit Camargue from today's delta proper.

The Rhône d'Orgon exhibits a decidedly immature channel pattern. Widths are notably variable from place to place along the channel and show some tendency to widen on reaches and narrow on bends. There is a curious asymmetry in the accentuation of bends. Along the western side of the Rhône d'Orgon a belt of crevasse deposits of much older origin has blocked the development of bends effectively, accounting for about four kilometers of relatively straight channel. Swings toward the east have developed freely enough, notable cases existing near Château d'Astonin and Mas d'Icard. West of Mas Gelly bend accentuation has resulted in the development of an S-shaped meander.

Petit Rhône

Petit Rhône, as the name is generally applied today, is an extremely interesting composite channel. Its ends, the Fourques and d'Orgon channels, are comparatively new. The middle section consists of two elements, (1) a portion of the oldest, Tourradons, channel exhibited on the entire delta surface, and (2), part of one of its chief distributaries, the Silvéréal channel.

Crevasse deposits are many and agriculturally important along the whole Petit Rhône. These are low sandy ridges or cones extending more or less directly down the slopes of the natural levees. The soils are well adapted for cultivation of the vine and other crops. Practically every crevasse has determined the location of a large country house, "Mas" or "Château." Excepting breaks in the vicinity of Mas de la Fosse which lead to the old Tourradons channel, few important overflows have occurred along the right bank, a fact responsible for asymmetrical agricultural activities along the channel. The finest estates are restricted mainly to the Camargue side natural levee and the houses are located on crests of crevasse deposits. These form elevated strips which divide the Camargue into basins, locally called Pâtis, Marais, or Baisses, depending upon the degree of dryness toward their centers. Some of the wettest depressions between crevasses are more or less permanently flooded, so that they contain elongate étangs.

Rhône d'Ulmet

Rhône d'Ulmet, "3" in Fig. 10, is the oldest eastern Rhône channel on the surface. Part of its course has been identified by Gerin-Ricard (52–

363), but the majority of writers on the Rhône delta have overlooked it. Gerin-Ricard believed that it departed from the existing Grand Rhône at Beaujeu, about 14 kilometers below Arles. This possibility is indicated as "L" in Fig. 10. Field evidence lends little support to the recognition of this channel segment. The natural levees and decadent channel both lead upstream into Roubine de la Grande Montlong, channel "K" in the figure. The original head of Rhône d'Ulmet appears to have been about five kilometers below Arles.

Roubine de la Grande Montlong has been improved for drainage purposes within recent centuries and has a fresh channel today. This channel, however, is but an insignificant remnant of the stream responsible for the fine natural levees at its sides. These are used by the main highway between Trinquetaille and Ruines de l'Abbaye d'Ulmet and by the railroad to Salin de Giraud. Where they cross the natural levees of the Gageron head of the Tourradons channel, the latter are lower, less continuous, more eroded, and hence older.

At the time Rhône d'Ulmet was active the Albaron-Tourradons channel had either been abandoned or was fed by some head other than Gageron. Reasons have been advanced above in support of the belief that Gageron was the original head of the Albaron channel, being later replaced by Bastières and Triquette. Both of the latter lie west of Rhône d'Ulmet and either may have continued to function during the prime of d'Ulmet. It is even possible that the Forques channel had come into being by Rhône d'Ulmet times.

Roubine de la Grande Montlong now leaves Rhône d'Ulmet below Gageron and continues into the lowland of Marais de la Grand Mar. The railroad and highway keep to the levees of d'Ulmet as far as Valleneuve, where the latter are crossed by the natural levees of Rhône de Saint-Ferreol. Here the d'Ulmet levees are the older and its channel is blocked completely by the younger Saint-Ferreol course. The highway now leaves d'Ulmet natural levees for a relatively dry route along the eastern margin of Étang de Vaccarès, but the railroad remains on the levees for several kilometers more, finally leaving them near la Chassagnette. In this vicinity the old channel of Rhône d'Ulmet bears the name Roubine d'Aube de Bouic. At Fiélouse, there are two variants in the course.

The older channel below Fiélouse, "J" in Fig. 10, swings in a wide arc around the eastern side of Marais de Saint-Seren. This course has been recognized by Repelin (99–60) and is distinct in the field both with regard to levees and channel.

The more direct channel, with higher and drier levees, west of the

Marais, has been utilized by the highway. The course continues between excellent natural levees near Étangs du Fournelet and Redon to Pont des Écluses, where it becomes known as Bras de Fer.

The original flow in Bras de Fer was eastward from Pont des Écluses to Chamone, Grand Passon, and along the great meander loop known today as Bras Mort and Marais de l'Escale. The Grand Rhône has appropriated the old channel, with reverse flow direction, between Chamone and Grand Passon, and crosses it directly near Barcarin. West of Barcarin Rhône d'Ulmet flowed westward along the northern side of the settlement of Salin de Giraud and along a channel which is still plainly evident past the old tower of Faraman, Mas de Japon, and Ancienne Vigie de Faraman to a destination now obscured by cultural change in Salin de Giraud.

Though Rhône d'Ulmet has not been recognized previously in its entirety, its course is distinct and its levees are large and important agriculturally. Where it closely approaches the eastern border of Étang de Vaccarès drainage ditches across its natural levees reveal excellent sections of flood plain silt closely resembling loess in color, texture, and tendencies to form vertical faces, Fig. 18. This material contains a great many snail

FIG. 18.—Rhône d'Ulmet natural levee material, now a sea cliff about four feet high on the eastern side of Étang de Vaccarès, near Marais de Grenouillet.

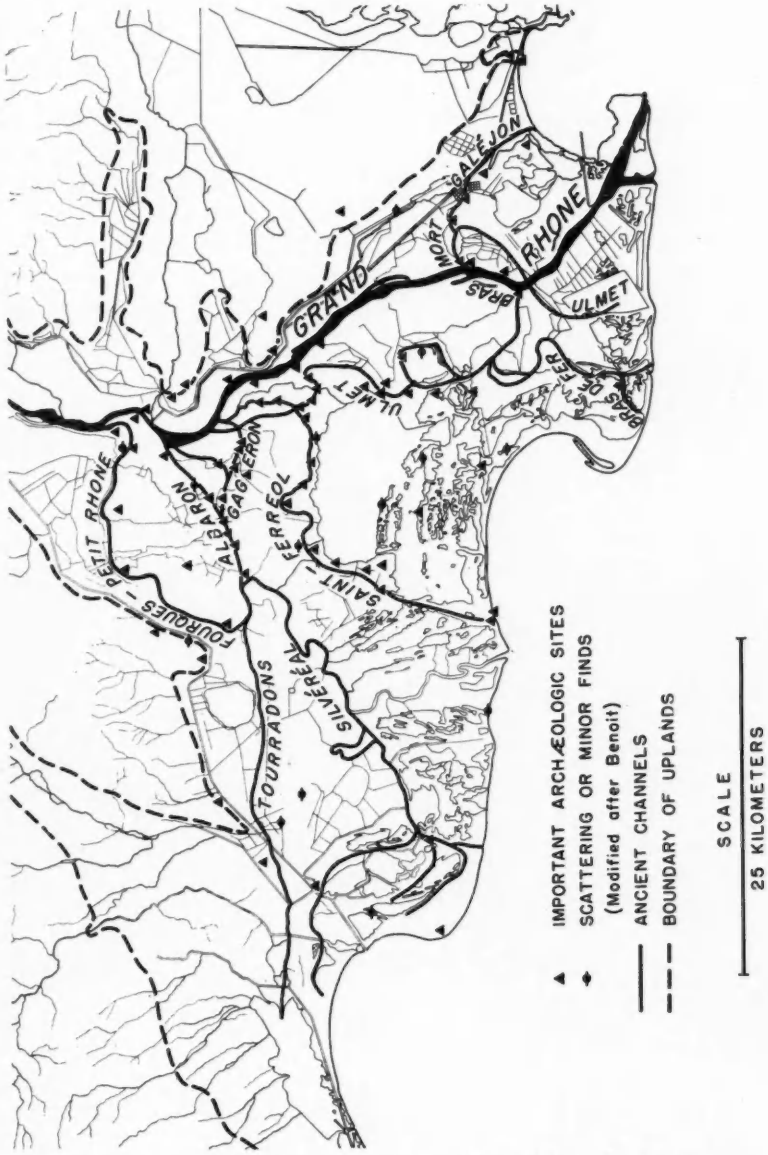

FIG. 19.—Archaeological sites in the Rhône delta and immediate borders.

shells and is highly calcareous. It is capped by quite maturely developed soils.

Numerous ruins from Antiquity attest the attractiveness of Rhône d'Ulmet for sites of habitation during Greek and Roman times, Fig. 19. This is not evidence, however, that d'Ulmet was in its prime at the time. Rhône de Saint-Ferreol was younger than any possible Rhône d'Ulmet head above Beaujeau, and as its natural levees contain materials dating back to the 5th or 6th centuries, B.C., Rhône d'Ulmet had lost at least the upper part of its channel by that time. The beheaded lower channel, however, remained navigable for many centuries and even today parts of it are in use.

Rhône de Saint-Ferreol

Rhône de Saint-Ferreol, "4" in Fig. 10, was one of the main Rhône channels during Antiquity and the most important route for navigation during the Middle Ages.

Roman ruins flank the entire course (51–8). At Carrelet and elsewhere are potsherds identified as being some 2500 years old and coins from the

FIG. 20.—Natural levee of Rhône de Saint-Ferreol, about six feet high, near Carrelet, now forming a sea cliff on the western side of Étang de Vaccarès. Potsherds and other materials layered in the silts indicate cultural occupance extending back some 2500 years.

3d century, B.C. (14–20). Excavations have uncovered buildings with floors at various elevations from slightly below sea-level to four feet above. Preserved in the natural levees are layers of pottery, stones, and débris derived from ancient settlements, Fig. 20. The average rate of accumulation of natural levee silts between the oldest archaeological materials and the time of abandonment of Rhône de Saint-Ferreol was about 0.3 feet per century. The actual rate of growth, however, was not uniform, most of the levee having been built before the start of the Christian Era. Ruins close to the surface, Fig. 21, date from about that time, so that the actual rate of alluvia-

FIG. 21.—Walls of granaries revealed by shallow excavation near Carrelet. These date from about the beginning of the Christian Era.

tion was about one foot per century during the Greek period and little has been accomplished during the last twenty centuries.

The Rhône de Saint-Ferreol remained navigable until 1430, when it was closed off from the Grand Rhône artificially (52–358). Some say this was in 1440 (99–65) and others place it in the 13th century (52–364). Possibly there were several attempts to close the channel in order to prevent floods on the fine agricultural lands along its natural levees. By 1543 the remnant channel was called Brassiere-Vielle, suggesting considerable channel deterioration by that time.

A person unschooled in flood plain geomorphology who views the channel of Rhône de Saint-Ferreol in the field would likely question the navigability of its channel as recently as during the Middle Ages. Alluviation has practically obliterated many miles of channel by filling to the level of natural levee crests. Many other miles of channel are indicated by only a gentle and narrow sag, which is somewhat accentuated by sparseness of vegetation, especially along the part west of Étang de Vaccarès (Fig. 22).

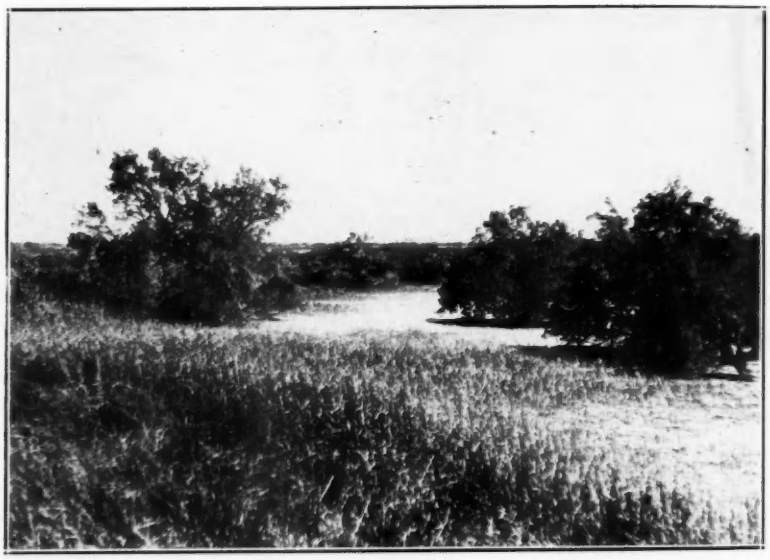

FIG. 22.—Channel of Rhône de Saint-Ferreol near Carrelet. This particular view, along the bottom of the sag indicating the position of the old channel, was taken at a particularly favorable spot for noting the barren appearance of channel clays.

In the coastal belt, toward les Saintes-Maries, no trace of the channel remains. Only upstream is the channel in any sense functional. Here it is occupied by relict streams, such as Roubine de la Petite Montlong. The entire channel is flanked by towers which were beacons for navigators using it during the Middle Ages. On the Rhône delta, as in southern Louisiana, the important lesson is evident that channel deterioration takes place so rapidly that channel condition observable today is an extremely poor criterion of width or importance a few decades or centuries ago.

While various heads have been postulated for Rhône de Saint-Ferreol, such as Brassière de la Cappe (99–64) and Roubine Triquette (52–364), the continuity of natural levees clearly indicates that at least the latest main channel led from l'Ange. The actual point of departure from the Grand Rhône was the head of the Gageron-Rhône d'Albaron, "G" in Fig. 10. In following the route of an old abandoned channel where it leaves a main river course, Rhône de Saint-Ferreol exhibits a pattern common throughout the lower Mississippi Valley. The place most likely for an important crevasse is a place where an old channel fill underlies the natural levee. Such places are weak, so that new streams originating in crevasses are likely to find their way into old courses.

Rhône de Saint-Ferreol followed the old Gageron course for about 1.5 kilometers, to l'Ange, where a left bank crevasse started off the new course. The success of this crevasse may be attributed to the fact that the Gageron course downstream had already been blocked by transverse natural levees of Rhône d'Ulmet. Below l'Ange Rhône de Sainte-Ferreol makes a sweeping curve past Tour de Montmeillan and Valleneuve to Notre Dame d'-Amour. Near Valleneuve, about five kilometers below l'Ange, the Saint-Ferreol waters were forced to cross Rhône d'Ulmet natural levees for the reason that the crevasse at l'Ange led into a basin bounded on one side by the levees of the Grand Rhône and on the other by those of Rhône d'Ulmet. Where the crossing occurs the relationships between levees are perfectly clear. The Saint-Ferreol levees are the higher and fresher. The channel between them crosses the old d'Ulmet course without interruption.

Below Valleneuve levees and traces of relict channels indicate the position of Rhône de Saint-Ferreol plainly as far as Pont des Cinq Gorges, at the western end of Étang de Malagroy. Farther south only natural levees exist and these are in the form of a low ridge, le Levadon, extending to les Saintes-Maries.

Grau de la Fourcade, the original mouth of Rhône de Saint-Ferreol, was located south of les Saintes-Maries, about two kilometers beyond the existing shore (51–11). Remnants of levees in the Mediterranean were extant in 1820. Maps of the 17th century refer to them as Île Odor, Ogor, or d'Orgon (99–69). Even maps published as late as 1866 refer to the fact that land formerly existed at that place. The original Grau de la Fourcade of Greek and Roman times has long since been lost to wave erosion and subsidence. Potsherds derived from the old settlements along its levees are still being cast upon the beach at les Saintes-Maries in considerable quantities. An opinion that the original mouth of Rhône de Saint-Ferreol was located two kilometers east of les Saintes-Maries (51–11) is not substantiated by either natural levees or remnant channels.

Grand Rhône

Grand Rhône, "III" in Fig. 10, is the eastern channel between Fourques and the sea. Its upper portion, above Montlong, served in various capacities as Albaron, d'Ulmet, and Saint-Ferreol channels. Below Montlong it is a relatively new creation. This lower channel is indicated as "5" in Fig. 10. Gerin-Ricard (52–359) regards it as having been created in 1430, when the Saint-Ferreol channel was abandoned, but this is unlikely. Repelin is probably correct in the belief that various routes were established to the sea along an eastern fork of the Rhône in Greek and Roman times (99–57–60). One of these channels was probably contemporaneous with Rhône de Saint-Ferreol and also with some branch of the Silvéréal channel, so that three major mouths were functioning during at least part of Antiquity.

The comparatively straight channel of the oldest known Rhône, the Albaron-Tourradons course, suggests a very large stream, one possibly capable of carrying the entire Rhône discharge. Later channels are more sinuous, suggesting that each carried but a share of the discharge. Rhône de Silvéréal appears to have been the earliest channel to divert a considerable amount of water from Rhône d'Albaron and possibly was so successful that it robbed the Tourradons channel completely. By the time of Greek settlement Rhônes d'Ulmet and de Saint-Ferreol had become well established, for archaeological sites are numerous along their courses (Fig. 19). Tourradons and Silvéréal below Albaron seemed to possess less attractiveness. The delta had advanced well toward its present area by the beginning of the Christian Era. The latest additions were made along the eastern margin of the delta, in the lowland and open water between the Rhône d'Ulmet levees and the lower margin of the Crau. It was along this direct route to the Mediterranean that the Grand Rhône ultimately established its course. Some (99–57) have maintained that the original eastern Rhône departed from the existing channel in the vicinity of Champtercier and extended to the vicinity of Étang du Galéjon but geomorphological evidence fails to support the idea. Aside from the great meander loop of the older d'Ulmet channel, this low area is singularly free from natural levees and channel scars. Arguments in favor of the idea are based chiefly upon historical facts involving use of a Galéjon route for commerce.

Galéjon

Galéjon raises questions exactly similar to those of Stagna and St. Gilles. It was the important trade route between the Gulf of Fos and Arles (151–pl. XIV).

Arles, *Arelas, Arelate*, is called a city and important emporium by Strabo (114: 4.1.6). Its founding is shrouded with mystery. Malte-Brun (78–894) regards the Celts as founders in about 1500 B.C. Hyde (62–46) gives the credit to Sextius Calvinus, the date being 122 B.C., four years before the founding of Narbonne, which is regarded as older by most historians (97–128). Benoit (14–27) says that Caesar founded Arles in 46 B.C. This date likely has political significance only. It is probable that a settlement existed there long before the invasion of southern France by Greeks, Romans, or even the Celts. The last main rocky platform toward the mouth of one of the major streams of Europe was certainly an attractive site for man in any stage of development. The Greeks were secretive about Gaul (125–xxx; 142, 172) and their silence about Arles is by no means proof that the settlement was unimportant in their day. Aristotle knew that Rhodanus was navigable. Pytheas knew that tin from Brettanice was carried overland to the mouth of the river. As the first colony of Massilia (62–191), Arles was an important center by the dawn of Gallic history. At the end of the 4th century, A.D., Constantine made it his capital (14–32) and built an important aqueduct to supply it with water. Via Domitia, along the Mediterranean coast to Spain, Via Aurelia, from Rome to Arles, and Alpis Cottia, used by Pompey on a trip to Spain in 77 B.C., converged and met at Arles (62–46; 40). Marius built a canal between Arles and Fos, that the Romans used as the "economic mouth" of the Rhône (32–240; 73–302).

Settlements and landmarks clearly indicated Rhône de Saint-Ferreol and Rhône d'Ulmet as the natural channels most useful to navigators during Antiquity and the Middle Ages. Any natural channel, however, has many disadvantages. We have noted how Stagna, an artificial route in many respects, and not Rhône de Silvéréal served St. Gilles. A parallel condition obtained on the opposite side of the delta. Arles was served for many centuries by routes avoiding large natural branches of the Rhône. The two delta-flank routes terminated in inlets across offshore bars or beaches. Such inlets afford greater security to navigators than passes at river mouths for the reason that their channels are more permanent, being less subject to shoaling at times of flood. The channels through the marshes also had an advantage in the relative absence of swift currents. They were straighter than the natural channels, so led more directly toward their objectives.

Galéjon routes were canalized to a greater extent than the Stagna routes west of the delta. Marius constructed the first canal in 103–102, B.C. (14–18). This was done because the natural Rhône mouths "were becoming stopped up and difficult of entrance" (114: 4.1.8). "Upon admitting the greater part of the river" to the new channel, Marius presented it to the

Massiliotes "and the wealth they carried off from this source was considerable, because they exacted tolls from all who sailed up and all who sailed down it." The mouth of this channel was called Gradus Massilitanorum (99–59), later known as Fossæ Marianæ, or Fosses Mariennes (52–363).

Fos, *Fossis*, and the Spanish and Portuguese *Foz* are derived from the Latin *fux*, a river mouth. The Golfe de Fos and the town of Fos, *Foz*, derive their names from Fosses Mariennes, the mouths of the Galéjon routes.

Odor, *Dor, Roque de Dour,* or *La Roque,* is a small Cretaceous "island" rising above a "sea" of very recent marsh just west of the mouth of Étang du Galéjon. In Roman times it was one of the main settlements along the coast (14–25) and throughout the Middle Ages retained considerable significance as the toll gate for Galéjon routes. Rising to a height of 25 feet above sea-level, this "rock" was a good landmark for navigators, guiding them to the channel entrance. La Roque is abandoned and desolate today.

The Canal de Navigation d'Arles au Port de Bouc, built in 1842, is the equivalent of the canal constructed by Marius and follows the original route closely. Traces of the Roman canal have been found at many places, especially near Port de Bouc (73–302). The most recent economic mouth of the Rhône is Canal St. Louis, built in 1871. This canal is short, extending from near the head of passes directly eastward to the Gulf of Fos.

It is difficult to evaluate the discharge carried by the eastern branch of the Rhône in Antiquity. Pliny regarded the Massiliotic as the main mouth of the Rhône (98–101). The estimate is more probably from the standpoint of use than of actual discharge. It is also likely that the reference is to Fossæ Marianæ, a Galéjon route, and not to any true branch of the river. Reclus (98–102) says that the original canal to Arles followed a chain of lagoons, a condition indicating studied avoidance of any true stream channel. Observations in the field confirm the idea. Aside from the Galéjon route of the Middle Ages, which made use of part of Rhône d'Ulmet, the commercially useful water routes to Arles followed the lowlands and avoided larger natural channels.

The Galéjon route of Antiquity led along the existing Étang du Galéjon, Étang du Landres, and other low parts of the delta-flank depression extending to the vicinity of Arles. When the Grand Rhône advanced seaward along this belt, it remained west of the canalized lowland. The Galéjon route of the Middle Ages coincided only roughly with that of Antiquity. Instead of following the lowland north to Arles it cut across, through Bras Mort, "N" in Fig. 10, to the Grand Rhône.

Bras Mort

Bras Mort is an anomaly evident on any detailed topographic map. Its western part is a portion of Rhône d'Ulmet, between Grand Passon and le Radeau. The eastern part is either a crevasse channel, or an artificial canal, leading through the marshes to Étang du Galéjon. It served as the economic mouth of the Rhône from the 6th century, A.D., to 1559, when it was closed artificially (33–428). Small boats continued to use it until the middle of the 17th century (90–423). La Roque d'Odor served as its landmark and toll gate. Oldham (90–421) is correct in the belief that it was at no time the main eastern Rhône channel. Most literature on the subject, however, takes the opposite viewpoint. Beyond le Radeau no significant natural levees outline the channel. The channel seems to have been shoal, with depths of as small as 1.5 to 2.0 paces at several points, even at the time of maximum commercial use.

Bras de Fer

Bras de Fer, "M" in Fig. 10, was the mouth of the Grand Rhône for several centuries. Questionable relics from Antiquity have been found at various places along its natural levees (15–123), but the date of its origin is somewhat uncertain. Its economic significance appears to have been slight until about the middle of the 15th century. From this we should consider it as having had an enormous discharge, carrying such quantities of sediment that shifting channel and bar conditions rendered access difficult. Its passes faced the open Mediterranean and so fared unfavorably in comparison with those in the sheltered Gulf of Fos, leading to Galéjon routes.

It is likely that the Grand Rhône channel to Bras de Fer was established by a crevasse near Montlong when Rhône d'Ulmet was abandoned. The new stream took the lowland between Rhône d'Ulmet natural levees and the edge of the Crau. Had the channel been directed east of le Radeau it would have found an easy route to the Gulf of Fos and the latter would have been filled in short order. Advancing channels, however, in their blindness and lack of consideration of future consequences, often lead themselves into serious hydrographic difficulties. The Grand Rhône did so in taking a route southward into the basin outlined by Rhône d'Ulmet levees on three sides, between Pont des Écluses and le Radeau. Breaking through the northern, left bank, levee of Rhône d'Ulmet, near Grand Passon, it found the old channel, which it could follow either to the northeast or southwest. The former direction would have been downstream along Marais de l'Escale to the original d'Ulmet mouth. The latter led upstream, toward Fiélouse.

Eventually both directions were taken, Bras Mort resulting from the downstream flow and Bras de Fer from the upstream. Bras de Fer appears to have been established first and always carried the major part of the discharge. Its alluvial deposit added something like 100 square kilometers to the delta. Bras Mort may have been artificial. In any event its alluvial contribution to the delta was practically nothing.

In adopting part of Rhône d'Ulmet when creating Bras de Fer, the Grand Rhône reversed its original direction of flow for about nine kilometers. Bras de Fer swings in a long, gentle arc along a channel that eventually leads directly up the slope of the delta. Instead of following the course upslope the Grand Rhône crevassed out of the d'Ulment channel at Pont des Écluses and extended itself southward for over 18 kilometers. The exact distance to the original mouth of Bras de Fer is unknown for the reason that this particular stretch of coast is being lost rapidly to wave attack and the original end of the channel has been removed. A number of the original passes are still preserved in the coastal marshes and most of the gazes in this vicinity are low crevasse deposits leading from Bras de Fer natural levees.

FIG. 23.—Bras de Fer channel near St. Bertrand.

Bras de Fer alluviated rapidly. While its dominant pattern is that meandering, many evidences of braiding are present toward the coast. In Louisiana, braiding is always associated with rapid alluviation (107–1199).

The initial crevasse of the Grand Rhône from d'Ulmet took place near St. Bertrand and is followed today by Canal du Japon for a considerable distance. The channel is only partially filled today along much of its length (Fig. 23). Large oaks and other trees grow luxuriantly along its natural levees, which still rise several feet above the alluviated channel floor. The flatness of the floor is broken by low sand dunes, *tourradons*, that appear to be chiefly cultural in origin, resulting both from overgrazing and plowing fine, loose, sands and silts. Farther toward the coast, Bras de Fer levees are outlined by tamarisk trees and the more or less saturated and flooded channel is clogged by tall grasses (Fig. 24), dominant among

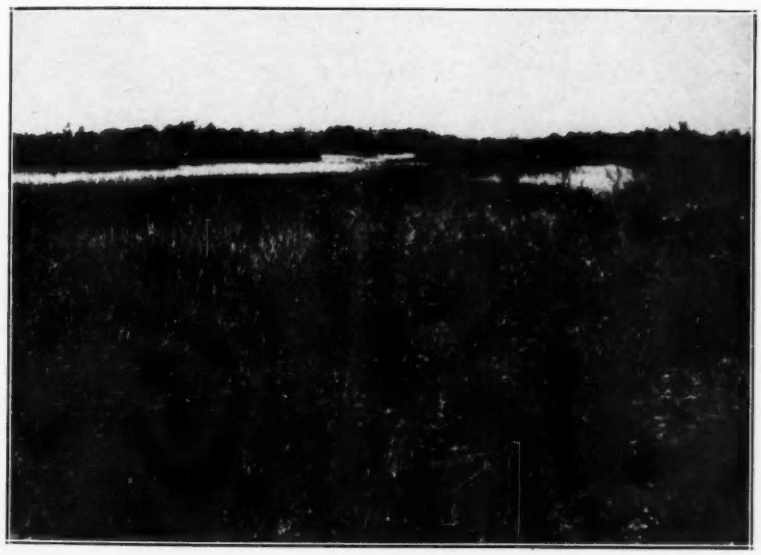

FIG. 24.—Bras de Fer a short distance south of la Pebre.

which is *Phragmites*. The lowest part of the channel, toward the coast, sinks below the level of adjacent marsh and is estuarine.

Above Bras de Fer the original Grand Rhône was located somewhat west of its position today. Evidences of the old channel appear south of Tour de Caseau and much right bank land, such as la Commanderie, Île des Pilotes, and la Louisiane, has been added during the last five centuries. Tour de

Manusclat has been removed so far from the channel as a result of this accretion that it was regarded useless as an aid to navigation by 1469 (90–422).

Bras de Fer was the economic mouth of the Grand Rhône between 1559, when Bras Mort was abandoned, and 1711, when the existing lower course was established (33–428; 73–129). It had some use even prior to 1559. Tour Belvare was built in either 1469 or 1472 (90–422), at Grand Peloux, below Bras Mort, and its only purpose could have been that of guiding boats using Bras de Fer. It thus seems probable that by the 15th century the mouth of Bras de Fer was sufficiently stabilized that shoals along the Galéjon-Bras Mort route were driving traffic toward it. The abandonment of Rhône de Saint-Ferreol, sometime between the 13th century and the year 1440, probably contributed to the adoption of the Grand Rhône by navigators.

Saint Louis Channel

Saint Louis channel is the existing lower Grand Rhône, "P" in Fig. 10. It dates only from the 18th century.

The inhabitants of les Saintes-Maries set out deliberately to divert Rhône de Silvéréal to the vicinity of their village but the fact that the other branch of today's Rhône also has an artificial mouth seems to have been accidental. A canal, Bras-des-Lônes, had been constructed from the coast to the left bank levee of Bras de Fer (16–203), apparently to reduce the hazards associated with an active smuggling trade. In some way a certain Eygadier has been blamed for negligence in permitting the Rhône to make its way into this canal during a flood (52–363). Most authorities place the date as 1711 (16–203; 73–129) but some say 1713 (52–363). All agree that by 1737 the new channel extended past Saint Louis, for a tower was built there at that date (99–59).

Channel Advance

Channel advance of the Saint Louis mouth of the Grand Rhône is ordinarily regarded as having been about eight kilometers in 26 years, one-third of a kilometer per year, or about thrice that of any main Mississippi River pass in an equivalent length of time. It is also generally believed that about three-eighths of the Grand Rhône channel between Arles and the coast has been added since 1711. Such estimates fail to consider the fact that Bras de Fer did not lie immediately on the coast. It was flanked by marshy flats for several miles beyond the crests of its natural levees and various old étangs and tidal channels were present in the marshes. Figure 25 is rep-

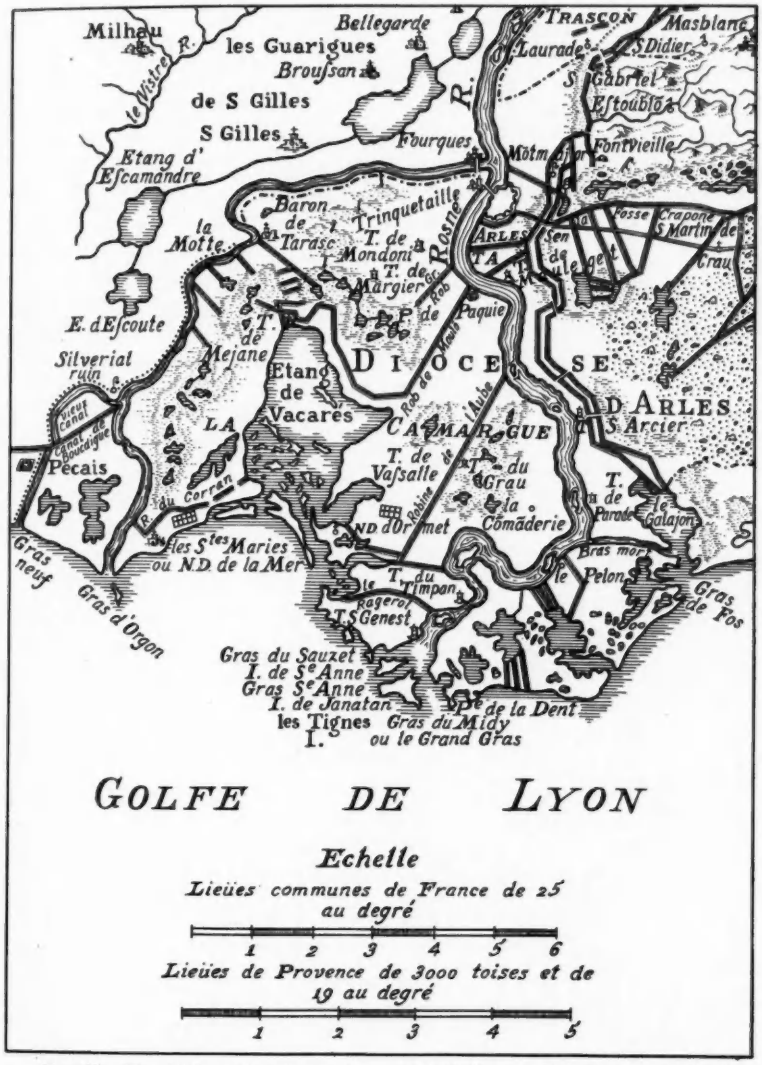

FIG. 25.—The Rhône delta, from the map of Guillaume Del Isle, dated October, 1715.

resentative of conditions at the time the St. Louis channel was created. The coast south of Bras de Fer had advanced about as far as it extends today. The heavy bars just below le Pelon and a large bay indicate the course the Rhône was to adopt. It is clear that we must not regard the advance of the St. Louis channel as having taken place into the Gulf of Lion. It was chiefly an adaptation to conditions already existing in the marshes. Only the building of natural levees and scouring of the channel were necessary to transform the lands of the 1715 map into essentially those we find today. The natural levees now rise a meter and more above marsh levels. Modern changes are associated with the development of new passes.

It is doubtful whether there is any merit in any of the numerous references in literature as to the rapid growth and advance of the St. Louis channel. The rate of advance has been used in such speculations as have led to the conclusion that Arles was the mouth of the Grand Rhône 5,478 years ago (29–102). This is exactly in line with the fallacious conclusion that New Orleans was the mouth of the Mississippi River at the time of Christ, a conclusion which has been advanced wholly upon the evidence of the advance of Southwest Pass. In 1900, de Lapparent estimated the advance of the St. Louis channel as averaging 57 meters per year since 1737 (71–225), which is a small fraction of that ordinarily postulated for the interval, 1711–1737. Even this estimate overlooks the fact that Tour de St. Louis was located well inland at the time of its building. Any such estimate ordinarily refers only to the advance of one particular pass, usually the one protruding farthest into the body of water being invaded. At a river's mouth, however, conditions are more complicated. One pass advances for a while, then yields to another. Each new pass advances rapidly for a year or two and then growth slackens. As time goes on it attains a stability, both with regard to shoaling and advance. Averages mean but little under such conditions, particularly when they apply to greater lengths of time.

Mouth of the Grand Rhône

The principal features of the St. Louis channel had become established by 1842 (Fig. 26). The three main passes were le bras de Piémanson, on the west, le bras de Roustan, in the center, and le bras de l'Est, with several outlets, grau du Levant being the most important (99–62). Between and along the sides of passes were low sandy islands, or "theys."

Most of the theys have been documented as to date of origin. So far as known each represents the sand accumulation around an old wrecked ship which was driven or guided into a shoal while attempting to negotiate the river mouth. Such names as Tartane, Roustan, Balancelle, and l'Annibal

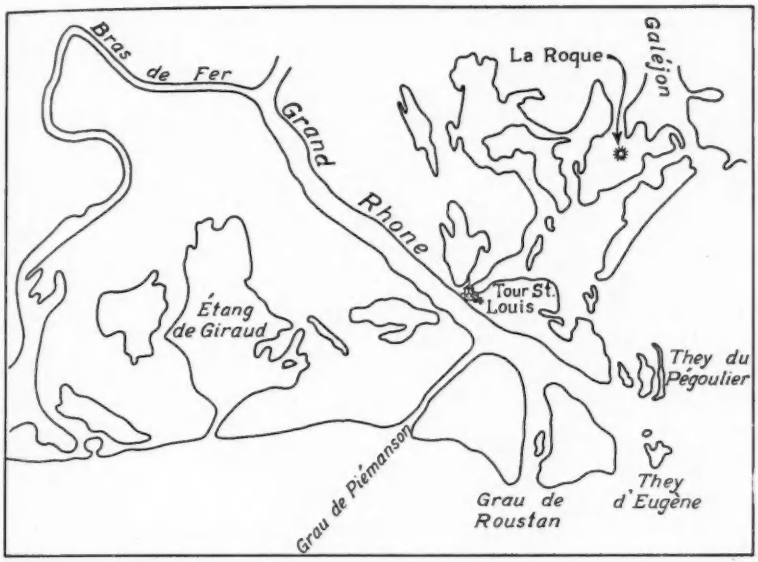

FIG. 26.—The mouth of the Grand Rhône, from a chart of les Ingénieurs Hydrographes, in 1842.

are those of the ships concerned. They de Roustan was formed toward the end of the 18th century and They d'Eugène in 1837, just prior to the construction of the map shown here as Fig. 26 (29–102).

An extremely competent hydrographer who wrote under the name le citoyen Le Creulx, at the beginning of the 19th century made the important generalization that a river with many mouths is not likely to be navigable and advocated the building of barriers across the minor passes of the Grand Rhône in order to concentrate the water into a single channel, which should be kept clean and deep as a result (73–303). The plan was put into execution half a century later, with highly satisfactory results. Grau du Levant was kept stable and deep enough for navigation (99–62). In 1893, however, a breach in the confining wall admitted flow into Bras de Roustan. Two years later this channel was 60 meters wide and from four to seven meters deep. By 1903 the width was 200 meters and the depth eight meters. Nature had seemingly provided a fine channel without jetties and Grau du Levant was allowed to deteriorate. The principles of Le Creulx, however, remained true. The new channel had only illusory advantages. Shoals

at its mouth now restrict depths to about one meter and uncertainties in their positions have driven navigation back to artificial economic mouths. Existing conditions are shown in Fig. 27. Grau de Roustan reigns supreme

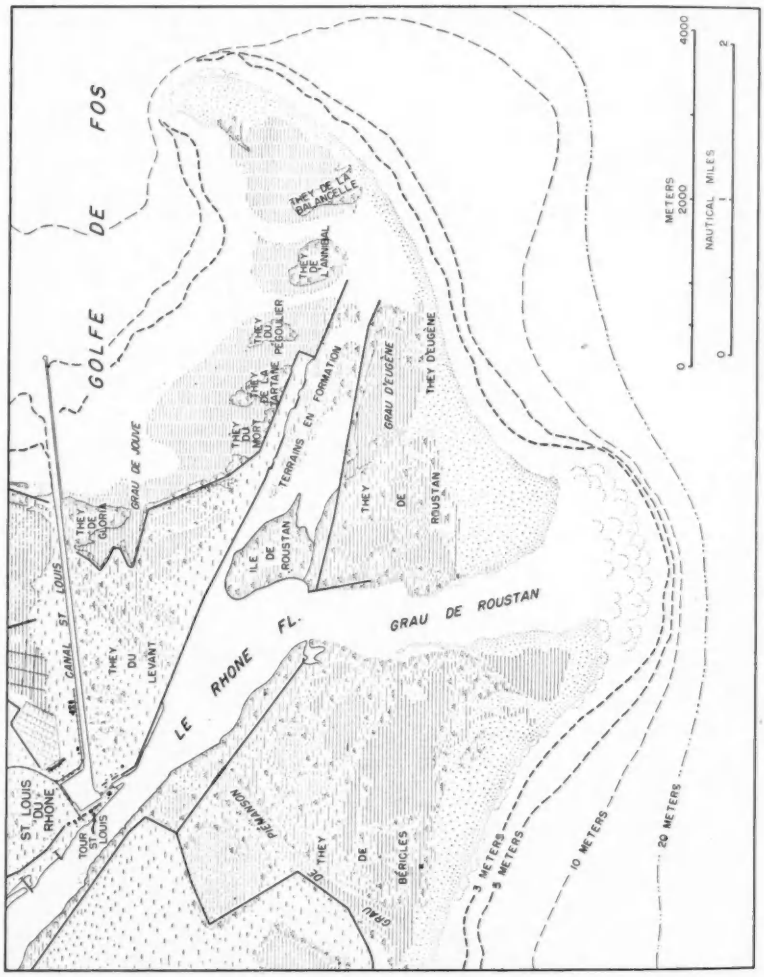

FIG. 27.—The mouth of the Grand Rhône, adapted from the August, 1935, edition No. 4, chart of the Service Hydrographique de la Marine.

as the outlet, but in an irresponsible and totally useless manner. Canal St. Louis is the economic mouth of the Rhône.

Summary

Detailed study of channels now present on the surface of the Rhône delta reveals an interesting history of sequence during the last 5,000 years or so, the "modern" portion of "Recent" time in the physical history of the delta.

The significance of any former stream course is to be judged on the basis of its natural levees and their pattern rather than on the condition of its channel as it exists today. Channels that were once the whole river, or that carried a large share of its total discharge, are relatively straight or exhibit meander patterns in which individual loops are large, often many miles in length. Rhône d'Albaron, Rhône de Saint-Ferreol, and Rhône d'Ulmet may be cited as examples. Channels of less consequence exhibit shorter meander loops along their more tortuous courses. Roubines de la Triquette and de la Petite Montlong are good examples. The lesser channels also have narrower natural levees. A fresh channel means more recent use, rather than greater significance. Some of the major channels during the Middle Ages have so deteriorated as the result of alluviation that their positions are today obscure. Rhône de Saint-Ferreol near les Saintes Maries is a good example.

The lower few miles of both Grand and Petit Rhône channels are artificial in origin. The former was determined by a smuggler's canal that became an active crevasse in the year 1711 and the latter was constructed deliberately by the inhabitants of a town in 1552. Farther upstream both of these channels are compound affairs, being in part developed along new courses leading from ancient channels and in part along segments of ancient channels themselves. Each stream offers an example of an ancient channel adopted and revived but with direction of original flow reversed.

Historical records and prehistoric artifacts are extremely useful for dating periods during which most of the channels experienced greatest activity. If used without a background of field experience, however, they could well prove treacherous and lead to false conclusions. One of the main reasons for this is the fact that human activities are more concerned with routes for trade, areas of settlement, and places of spiritual or political significance than with such matters as discharge volumes of water in channels. One might readily conclude that Stagna, a delta-flank route through small lakes and marsh channels on the western side of the deltaic plain, was once an important branch of the Rhône, or that Galéjon, a similar route on the east, was another. Uncertain channels and shifting shoals always discour-

aged navigators from using the larger and more active mouths of the Rhône. The economic mouth today is a canal. This was also the case during parts of the Middle Ages and during the early part of the Christian Era.

The discussion of channel sequence has been detailed and, in places, tedious. The pioneer nature of the conclusions practically demands that this be the case. There is much scattering information concerning channel development and abandonment in literature but there seems to be no full discussion of the entire problem elsewhere. Several of the channels have escaped previous notice entirely. The fact that practically every departure from channel straightness in the entire delta has a rational explanation has been overlooked. Precise identification of channels under discussion requires the introduction of many insignificant place names. Reference to Figure 10 will assist in their identifications in Figures 11 or 12. Care has been exercised in the restriction of place names to those shown on the 1 : 50,000 Carte de France, issued by the Service Géographique de l'Armée, in order to assist any future investigator who may wish to check conclusions in the field, or upon detailed maps.

BASINS

The upland divides of the Rhône delta are the crests of natural levees flanking all branches of the river from the largest distributary to the smallest crevasse channel. These attain elevations of over four meters above sea-level toward the head of the Camargue and gradually fall to that datum near the coast. Adjacent flood plains stand low in comparison. Even above Arles, toward Marais desséchés des Baux, Étang de Figuerolle has an elevation of but two meters and this elevation is repeated across the river at Mas de Fangues, about three kilometers south of Bellegarde. Various places near St. Gilles lie but a meter above sea-level, whereas nearby natural levees rise to four meters. Under natural conditions a great deal of land near the coast stands almost exactly at sea-level and the floors of étangs somewhat below. Artificial drainage accounts for some actual land surface below sea-level, kept dry by pumping.

Natural levees prevent tributary inflow along all branches of the Rhône in its delta. They divide the surface into a rather complex group of shallow basins.

Between the Grand Rhône and the Crau, east of the delta proper, are Plan du Bourg and la Coustière de Crau. These are the lower end of a major basin east of the Rhône natural levees. It extends northward past Arles into the wide flood plain that continues along the southern side of the Durance. A similar feature west of the delta is the Stagna basin, which extends past St. Gilles into the broad plain terminated northward by the

Cretaceous cliffs near Beaucaire. The lower part lies between the Tourradons channel and la Costière. Farther south, toward Aigues-Mortes, are several irregular basins between cheniers and natural levees. The Petit Camargue is a triangular basin between Rhône d'Orgon and other Silvéréal channels. The Camargue itself is the delta proper and is really a large basin of triangular shape between the levees of the Grand and Petit Rhônes and the beaches along the Mediterranean. It is divided into numerous smaller basins, the flooded parts of which are the étangs.

Terminology

Terminology of an interesting type always arises in connection with the subdued landforms and hydrography of a flat region. The Rhône delta is particularly rich in this regard, having names derived from several different languages and at vastly differing dates. Words of Provençal origin predominate. Many have such precise and useful meanings that they could well pass on into other languages as scientific terms. While the following list is by no means complete it is highly useful in describing the basins of the Camargue and in understanding detailed maps of the region.

Bauque refers to the tree-covered banks of major channels, hence to the major natural levees. *Ségonnaux* (secundum aquam) are the higher prairies or pastures between basins, hence the natural levees of abandoned river channels or the deposits of important crevasses. *Gazes* are "hybrid lands" toward the coast, supposed to be neither wet nor dry, and are the low natural levees of various minor channels or crevasse deposits so low that they can be distinguished only with difficulty from the surfaces of adjacent marshes.

Engane is wet marsh bordering the étangs or lower parts of unflooded basins. *Plaines d'enganes* refer to low country of "black bulls and white horses," the lower parts of the Camargue. *Sansouries* are flats displaying efflorescent salt when dry. The process by which the salt appears is called *salant*. Repelin (99–81) says that Vidal de la Blache misused the term in applying it to the *theys*, the low islands marginal to active passes. *Baisses de baisso* are the low étangs toward the coast, some of which are at times dry. *Lônes* are coastal lagoons, especially those of irregular outline. The elongate lagoons behind offshore bars are ordinarily called étangs, a term also used for describing any shallow lakes of the region, whether permanently flooded or not.

Montilles are lines of dunes. Many are low and represent old shores. The largest and most continuous examples would be called cheniers in southern Louisiana. Some montilles are nothing more than sand in irregular hummocky patches. *Tourradons* are little hummocks of wind-blown sand.

Many occur in old channels and in places that have been disturbed culturally. *Levadons* are small banks of very slightly elevated land along both artificial and natural channels. If supporting trees, the higher and more continuous examples would be called chenieres in southern Louisiana. *Bri* is fairly compact and somewhat calcareous clay not encrusted with salt.

Marais means marsh, but is applied to a whole basin if predominantly marshy. *Pâtis* implies greater usefulness for grazing and is applied to the higher parts of some marshes. *Marais salant* implies true salt accumulation, not simply salt marsh in its loose sense, as in English. *Marais pré salé* are brackish marshes.

Cordon littoral is a scientific term originated by de Beaumont and widely adopted for ridges of sand and gravel that originally accumulated along the shores of the sea. It covers both active beaches and cheniers and some have restricted it to beaches formed on seas with little tidal action.

Eastern Basins

The basins east of the Camargue extend well beyond the head of the active delta. Upstream they reflect the typical pattern of alluvial drowning, estuarine-like heads extending back between the Crau and the Alpilles for over 20 kilometers and for even a greater distance along the flood plain of the Durance, on the northern side of the Alpilles. La Montagnette, Petit Crau, Montmajour, the Cretaceous hill of Arles, La Roque d'Odor, and several other outcrops of bedrock or terrace deposits stand as islands in the alluvium of the basins.

The lower parts of the eastern basins, Grand Plan du Bourg and la Coustière de Crau, closely resemble the Camargue in all respects. Behind the sandy beach of the Gulf of Fos are low étangs, salines, gazes, plaines d'enganes, and other features characteristic of coastal Camargue. Farther upstream are marais, ségonnaux, and other features associated with higher lands in the Camargue. Such features grade northward into excellently drained flood plain.

The eastern basin region nearly pinches out between the natural levees of the Grand Rhône and the border of the Crau some distance south of Arles. Gravels washed down from the Crau spread over the floodplain surface and yield landscapes such as the one shown in Fig. 28. The heavy forest in the background marks the crest of the natural levee. In the foreground is an area sharing the desolate appearance of the Crau, the reason being a thin veneer of gravel. Some of this land is useful for cultivation of the vine. Numerous springs along the border of the Crau, *laurons,* furnish an excellent water supply (129–200).

North of Arles the low basins east of the Rhône spread back through

Marais du Grand Clar to Marais desséchés des Baux. Artificial drainage has converted former étangs into marsh and meadow here. Alluvial fans from nearby highlands in the district east of Château de Grand Barbegal separate the marshes into a series of more or less distinct basins. Toward Mouries and Château de Beauregard, at the head of the old estuary, alluviation is covering former marshes with materials derived from upland slopes and the territory rises gradually into the gentle slope of a long alluvial apron. Here it is high and dry and agriculturally prosperous.

Characteristics of alluvial drowning extend up the Rhône Valley, around the western end of the Alpilles, and along the flood plain of the Durance. Several wet meadows, paluds, occur in the lower parts of individual basins between natural levees of both active and abandoned channels of the Rhône and the Durance. Relict channel scars are numerous on the flood plain. Soils and crops are sharply localized with respect to these old stream courses. The gravels of old channels and natural levees are used chiefly for vineyards and orchards. Lighter silts and sands support extensive truck gardens. The heavy soils toward the centers of basins between channels are in many cases unproductive enough to be turned over to grazing.

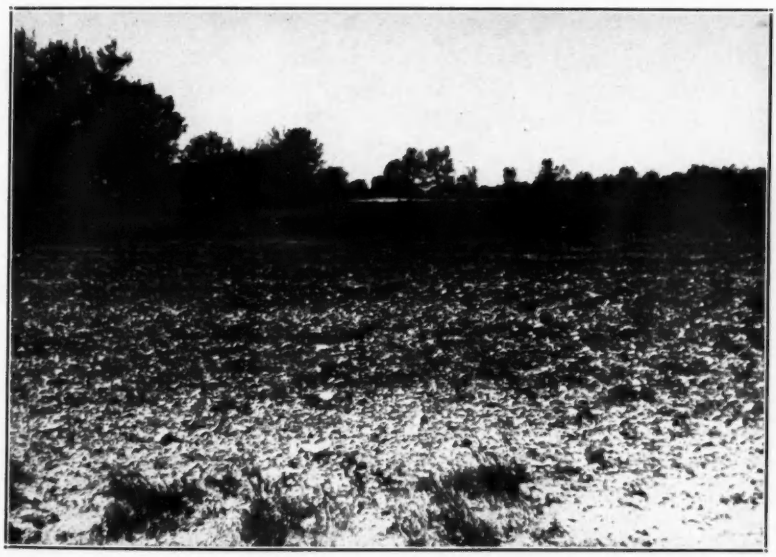

FIG. 28.—Superficial cover of Crau gravels on the Rhône flood plain at Grand Galignan, about 12 kilometers below Arles.

Historical Modifications

It is insisted by Lenthéric (75; 76) and others that in Roman times a great marais, with extensive étangs, extended from Arles to the sea. A similar low and largely flooded territory is said to have extended northward from Arles. Castelet, le mont d'Argent, Pierre-Feu, Trebouille, Montmajour, and la Montagne de Cordes may have been islands in an inland sea (99–57). An extreme viewpoint maintains that even during the Middle Ages one large étang extended from Eyragues, on the Durance flood plain, to Fos, on the coast (99–118). Though these eastern basins were undoubtedly less alluviated and wetter in the past than they are today, such statements appear to be exaggerations. Étangs certainly existed above Arles and extended along the lowland between the Alpilles and the Crau for a considerable distance toward Mouries. An Abbé of Montmajour commenced draining them in the 13th century and the project was finally effected by a Dutch engineer, Jean Van Enz, in 1640. Other étangs existed in the Durance flood plain but the maze of relatively high natural levees of abandoned channels in that territory precludes the possibility that any great number of them were effectively connected.

The navigators of the shallow waters east of the Rhône were called Utriculaires. Those living in Arles, or its vicinity, apparently had a monopoly on inland navigation toward the coast, while another group centered at the western end of the Alpilles carried on the traffic between Arles and various points along the Durance. These activities started at an early date.

Much speculation has been aroused by the finding of a Roman tombstone bearing the inscription "Fronton, Curator of the Marins of the Durance," at St. Gabriel, near the western end of the Alpilles (79–46). What were the "Marins?" Were they more or less connected seas or only Durancian channels? It is agreed that the Utriculaires used very shallow draft boats, capable of navigation through shallow étangs. That there was considerable water in the territory is well authenticated by references to Tarascon as an island during even the Middle Ages. On the other hand, Durancian channels of very recent date so divide the flood plain into shallow basins that the probability of extended navigation for any considerable distance up the valley seems remote. Baulig (8–499) has identified St. Remy, Vedènes, de Bédarrides, and Bonpas (now existing) Durancian channels. All of these appear no older than Antiquity at most. Any one of them might have been active during the Middle Ages. The river has wandered freely over its flood plain. Fronton and his successors for many centuries might well have been interested in navigable branches of the river, rather

than in the étangs of basins between its natural levees. It is supposed to be well known that navigators during the Middle Ages used the Durance as far upstream as Pertius (98–97). Even until 1908 there was some rafting in this tempestuous stream (96–40).

The rapidly building alluvial cone of the Durance is responsible for the position of the Rhône along the western side of its valley in the vicinity of Avignon. Floodplain scars suggest that not long ago the river flowed along a route between la Montagnette and Petit Crau. Though the Gardon is a tributary from the west, traces of its channel pattern occur east of the Rhône, near Vallabrègues. Not only has the Rhône been shoved against the valley wall by the advancing cone of the Durance but also it has suffered interesting channel pattern changes, being blocked above the Durance confluence and braided downstream as far as Île Pilet, about half way between Tarascon and Arles.

Western Basins

The basins west of the Camargue and Rhône fall into three groups. The basin farthest north, the plain between Bellegarde and Fourques, is essentially one shallow depression. It is separated from basins to the south by a narrow strip of lowland between the levees of the Petit Rhône and the Costière near St. Gilles. Natural levees of the Tourradons channel separate the main southern basins, Stagna lying to the north and a complex group, including the Petite Camargue, to the south.

Small coastal basins near Aigues-Mortes are related essentially to alternating advances and retreats of the shore. Being bounded by beaches or cheniers they are elongate in comparison with basins enclosed between natural levees. The sandy ridges between basins are intensively used agriculturally, conditions being excellent for cultivation of the vine. The floors of all basins south of Aigues-Mortes are relatively low. Large areas are étangs and their marginal salines require constant vigilance with regard to destructive flooding. East of Aigues-Mortes, Grand Palus is one of the largest continuous wet marshy tracts of the Rhône delta region.

Stagna has been described above in considerable detail in connection with its use as a route for navigation during the Middle Ages. Alluviation has altered it considerably within recent centuries. Only Étang de Scamandre remains as an extensive body of water. The low Marais du Crey, to the west, is too wet for pasturage at most seasons. In Louisiana it would become valuable for muskrat trapping and probably return a greater revenue per acre than nearby agricultural land. Regional subsidence has converted much of the Tourradons levee into sansouries. The presence of efflorescent salts had led many to the hypothesis that the strip of relatively high ground

is a beach and not the position of an old river course (16–205), the salt being considered as residual within old lagoons now converted to marais (105–320). Such notions are fallacious, as will be shown later.

Petite Camargue

Petite Camargue is a 9,000 acre triangle whose apex is the junction of Rhône de Silvéréal and Rhône d'Orgon and whose base is the coast between graus d'Orgon and Neuf. Its heart, Étang des Fourneaux, on the basis of many similarities, has been likened to Étang de Vaccarès of the Camargue (99–80).

Nearly half of the surface of the Petite Camargue is water. The étangs are highly irregular in outline and most of them are connected into two great systems, separated by marsh and low dikes along a belt running meridionally through the central part of the triangle. The proportion of water is slightly greater west of the central marsh. This region has received fewer crevasse deposits during recent centuries than the eastern area. The whole Petite Camargue exhibits the effect of subsidence sufficiently pronounced to extend its étangs well beyond their original shores and back along its original marshes. Such low belts of dry land and marsh as remain are either crevasse deposits or chenier remnants. The "regional grain" imparted to the territory by the presence of these features is one trending slightly west of north, or about parallel to Rhône d'Orgon and the grain of the territory east of it in the Camargue as far as Marais de la Sigoulette. Both cheniers and crevasses on the southern side of Rhône de Silvéréal trend in the same direction. Étangs along the coast have been closed by the broad sandy beach of the Mediterranean and the inland advance of montilles is restricting their southern extent rather notably. Few outlet channels reach the sea.

Aside from some excellent farms along the natural levee of the Petit Rhône, habitations are few in the Petite Camargue. It is an isolated, inaccessible region that supports what is by all odds the most interesting wild life in France, including many rare European and African types of birds (42; 61).

Basin of Bellegarde

Bellegarde, northeast of St. Gilles, stands in physical contrast to the Petite Camargue. In the latter case we have the wettest of all basins of the Rhône delta region and in the former, the driest. Nearly all of the Rhône flood plain between Beaucaire and the Fourques channel is rich agricultural land. A few lower parts are wet enough to be pasture lands but the term "pâtis," which is used to describe several individual lowlands in the basin is a heritage from earlier times and is generally quite inappropriate today.

Alluviation below Beaucaire has been very rapid since the creation of the Fourques channel, whose natural levees form an effective barrier across the southern side of the basin. The original result of this barrier was probably that of impounding overflow waters at times of Rhône flood, but sediments settling from such waters gradually built up the basin floor to a height sufficient to permit efficient drainage by canals leading past St. Gilles to Étang de Scamandre. The last marshy shallow depressions between crevasse deposits, Marais de la Castagnette and de Bellegarde, were drained at the end of the 18th century (90–407).

Breaks in the Rhône levee have from time to time flooded the basin of Bellegarde and hastened alluviation. The last main break occurred in 1841, when sand up to half a meter deep was deposited over a considerable area below the crevasse. The owner of Thieuloy became alarmed when the sand started to form low dunes, and planted rows of trees to stop its movement. Ridges as high as seven or eight meters soon formed along the tree rows. His successor cut down the trees and the dunes disappeared in less than a year (105–320).

Camargue

Île de la Camargue, the "island" defined by the Grand Rhône, Petit Rhône, and shore of the Mediterranean, is the Rhône delta proper (13; 110). It includes less than half of the 185,000 hectare deltaic plain near the mouth of the Rhône (98–101).

Estimates of the area of the Camargue are highly variable. To some extent this reflects the difficulty of determining the exact shore line, especially in the vicinity of Pointe de Beauduc, and the area of étangs subject to wide fluctuations in size between wet and dry seasons. There is also the question of whether territory immediately west of the mouth of the Grand Rhône should be included. In ordinary practice the boundary of the Camargue is placed along Bras de Fer and land between it and the Grand Rhône is called Île du Plan du Bourg. Most authorities consider the total area of the Camargue as 75,000 hectares (51–3; 96–43; 99–69), but some place it at 72,000 (97–190). If Île du Plan du Bourg is excluded it is about 56,000 hectares.

The High Camargue, the rich agricultural land toward the head of the delta, has an area of about 20,000 hectares. In the Camargue proper about 46,000 hectares are solid land and 16,000 are in use agriculturally, divided between grain (7,500), the vine (5,500), and pasture (3,000) (33–431). About 40,000 hectares are unused, 10,000 of which may be considered as other than solid land. The estimated area of étangs and wet marshes is 29,000 hectares (99–69).

The area of the central body of water, Étang de Vaccarès, *Valcarès*, or *Pichoto Mar* (*Petit Mer*), is ordinarily considered as 12,000 hectares (31–49; 54–330), but much of the bed is dry under ordinary conditions and only 6,480 hectares are covered by water most of the time (99–76). *Grand Mar* describes an expanded Étang de Vaccarès, pictured as extending to shores well beyond existing limits, particularly toward the north (35–411). There appears to be no factual basis for the rather widespread belief that Grand Mar gradually shrank to the present limits of the Vaccarès.

Alluviation and Subsidence

Oldham (91–74) believes that most of the Camargue was elevated land, high and dry, during Roman times. He makes much of the point that ancient buildings were located on solid surfaces, disregarding the fact that they were confined to natural levees that are also solid today (Fig. 19). He considers land now exhibiting "more impressive solitude than the ocean" as a Roman granary (90–403). The end of such conditions is supposed to have come with pronounced subsidence in about 700 A.D., leaving the Vaccarès open to the sea until the 17th century. Reclus (98–129) also states that "the granary of the Roman army" has been transformed into "a region of pestiferous swamps."

Repelin (99–56) disagrees sharply with Oldham's conclusions, stating that the étangs and marais were even larger during Middle Ages than now. George (51–12) considers Oldham's conclusions as unsound and criticizes their basis, which is chiefly cartographic. Benoit, who probably knows more about the archaeology and cultural development of the Camargue than anyone else, says that the Camargue was prosperous from the beginning of the Christian Era until the country was invaded by Normans and Saracens (14–29), at about the date of decline regarded as due to subsidence by Oldham. Benoit attributes the early 17th century return to prosperity in the Camargue not to uplift of the land but to a returning population, resulting from the establishment of better political security. Most of the Mas and Saints names for natural objects in the Camargue date from about that time. The facts of ordinary history appear to be such that the physical history postulated by Oldham finds no support from the standpoint of agricultural activity.

The distribution of ancient Greek and Roman settlements, as judged from archaeological finds, indicates that practically all were restricted to natural levees in the lower Camargue (Fig. 19). In all cases they were on high ground. Rhône de Saint-Ferreol and Rhône d'Ulmet were the densely settled channels and along these there is no reason to doubt that the land has

been firm and dry for the past 25 centuries. These and the high natural levees of Rhône d'Albaron formed the chief "Roman granary" and today they continue to produce considerably more grain than other parts of the Camargue. The basins seem to have been avoided by the Romans to about the same extent that they are unuseful today.

Subsidence does not necessarily mean submergence. Alluviation built land upward about as rapidly as subsidence tended to lower it. A section such as is now exposed along the western side of Étang de Vaccarès and shown in Fig. 20, where layer upon layer of cultural material is incorporated in the natural levees of Rhône de Saint-Ferreol, illustrates the result of these opposed processes. The culture occupying the lowest layer exposed probably did so at an elevation essentially similar to that of today's surface. The fact that some of the archaeological deposits now occur at levels below that of the sea is proof of subsidence. The deposit above the lowest layers indicates an active alluviation. The stratigraphic succession of culture horizons indicates occupational continuity.

Saline Basins

Much misinformation regarding the Camargue results from failure to comprehend its geomorphological history. Picard, Gautier-Descottes, Dumas, and practically all earlier workers identified the natural levees of all prehistoric Rhône courses as old beaches and the shallow basins between them as detached parts of the sea. Saline efflorescences were cited in proof of the marine origin of basins, including not only those to the south but Stagna and basins in the High Camargue as well. From such evidence it was argued that the basins had been lagoons and that the natural levees were old shores. The total dissimilarity between such features as the levees of Rhône d'Albaron and Chenier Godesque was dismissed as representing only difference in age. Finding saline conditions existing in practically all basins having an elevation of less than two meters (66–4), some concluded that the entire Camargue has been part of the Mediterranean not long ago, or that it has suffered a submergence for ten centuries. Only within recent years have such blunders been corrected by the recognition of natural levees of abandoned channels by Denizet (52–7).

The salts in the basins of the Camargue have two origins, the sea and the Rhône (33–429). The sea salt came into the lower basins as the result of flooding, essentially under topographic conditions that exist today and which are made use of in the various commercial "salins." Salt from the Rhône is readily identified by its high potassium content. It gets to the basins of the Camargue through seepage, overflow, and various artificial devices.

There is no fresh water in the étangs of the Camargue today. Wells are brackish and people depend on cisterns of rain water (99–82). An elaborate network of canals irrigates about 6,000 hectares of land, using water from the Rhône. When river stage is low the canals are brackish. Prior to the construction of the "dike against the sea," a project advocated in 1850 by Surrell and Montricher, begun in 1855, and made effective in 1859 (33–431), the lower étangs were dry at times of north wind and flooded by Mediterranean water when the wind came from the south. There are thus natural sources for the salts of the basins of the Camargue under natural conditions today. In a climate with a hot dry summer saline efflorescences must characterize exposed flats of clay under such conditions. We need neither an old sea, with natural levee beaches, nor the curious mechanism advocated by de Beaumont, subterranean eminations associated with a fault extending from the mineral springs of Balaruc, near Sète, to those of Aix-en-Provence, to explain them (27–363).

The contour of sea-level lies immediately behind the dike that keeps the sea out of the Camargue (99–7). The floor of Étang de Vaccarès lies about 1.6 meters lower (48–3). No real flooding from the Mediterranean has occurred since 1856 (21–460). Waters in the étang have become somewhat fresher, a fact regarded by some as injurious to health, possibly shortening life from 10–19 years (98–112). It has been suggested that the étang should be reconnected to the sea, as was done for Étang de Mauguio, with results said to be beneficial to local inhabitants.

Modern Stratigraphy

From the geological standpoint there has been a rather thorough misunderstanding of the physical history of the Camargue, expressed in an attempt to differentiate between "older" and "newer" alluvium. The distinction has been made on the Arles sheet of Carte Géologique de la France and is followed in nearly all geological literature on the Camargue (91–66). Stated simply, the cheniers and some of the natural levees are regarded as "older alluvium" and the rest of the surface as "newer." Compact bluish clay is regarded as "older alluvium" by some writers. Attempts to rationalize this distinction have resulted in explanatory complexity altogether out of line with the simplicity ordained by nature. Both terranes are not only "Recent," but are actually "modern," in the geological sense of that word. To interpret the distinction between them as even remotely equivalent to that between Alluvium and Diluvium is absurd.

Another serious distortion of physical history follows the rather general practice of regarding all shell bearing beds as marine in origin. The writings of Denizot are so colored by this argument that they lead to impossible

conclusions as to the evolution of the surface of the Camargue. The shells in question are chiefly *Cardium* and *Paludestrina*, the species being those now living in brackish water in the immediate vicinity. These shells constitute an important element in the beaches of étangs in the lower Camargue and of Étang de Vaccarès. Finding them incorporated in natural levee silts is by no means valid evidence that uplift has occurred, so that marine beds have been exposed above sea-level at such places as Combet, near Albaron, les Saintes-Maries, or anywhere else (91–70; 34; 35). Storm waves, floods, and even human activities account for the incorporation of shells in the natural levees. The significant fact about all such finds is that no truly marine types have been reported.

Marine shells occur in the cheniers, along with gravels and sands cast up on these former beaches. That they are found above sea-level is not an indication of uplift. An examination of the existing Mediterranean beach reveals the fact that waves now cast shells and gravel to elevations of over two meters above sea-level as a common thing, and such areas as the beach south of Grau du Roi show them incorporated in the basal materials of active dunes. On the main road north of Aigues-Mortes an excellent marine fauna occurs in the basal deposits of Chenier Godesque. It is probably slightly lower in elevation today than at the time of its deposition. There is neither faunal nor petrologic similarity between these deposits and those of the natural levees near Albaron.

Subdivisions

Natural levees divide the Camargue into its principal basins. Those of Rhône d'Albaron and Bras de Fer determine its major subdivisions.

North of the Albaron levees is the High Camargue. Its lowest parts, separated by crevasse deposits, are Marais de Saliers, Marais du Pont Rousty, and Marais de Palun longue (Fig. 12). That the lower, central parts of these basins are relatively dry and are useful pastures today is due largely to a drainage project carried out between 1860 and 1870 (33–431). Basin margins have been alluviated by rather sandy deposits, especially at Tête de la Camargue, near Trinquetaille, and along the Petit Rhône, so that they are excellently suited to cultivation of the vine. The summits of little hills in rolling "crevasse topography" reach elevations as high as 4.7 meters above sea-level and are excellently drained. A typical landscape is shown in Fig. 29.

To the east of the levees of Bras de Fer, at the southeastern corner of the Camargue, is Île du Plan du Bourg. This low region represents almost the opposite extreme from the High Camargue. Saline de Giraud, the

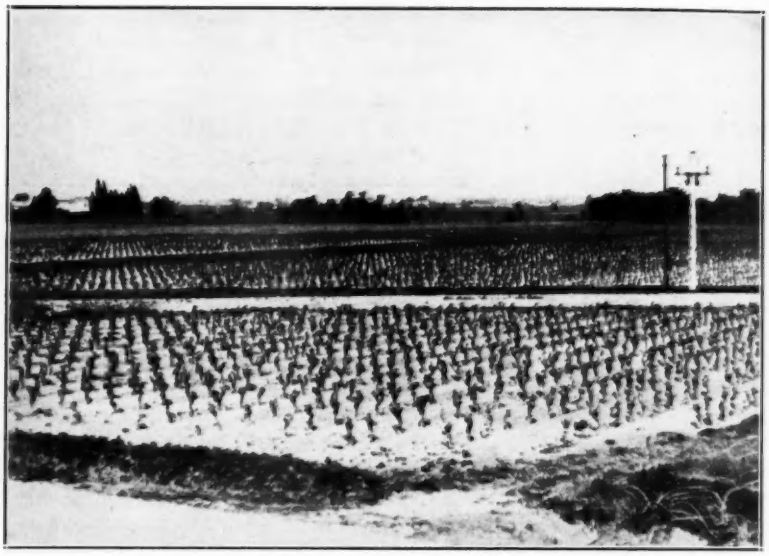

FIG. 29.—Vineyards in the High Camargue, near Trinquetaille.

most extensive salt works of the delta, occupies a large part of the basin and land away from the crests of the relatively narrow natural levees consists mainly of sansouries (Fig. 30). *Salicornia macrostachya* and *Statice bellidifolia* are the dominant plants at lowest elevations. A few centimeters higher are *Salicornia fructicosa, S. sarmentosa* and *Juncus acutus.* At 10 centimeters above the salt flats the vegetation is dominated by *Schœnus nigricans.* Étang borders support dense stands of *Phragmites gigantea. Tamarix gallica* takes over the low banks of ditches in this "domain of rabbits, bulls, and wild horses" (88–36).

The main Camargue basin surrounds Étang de Vaccarès. Natural levees of Rhône de Saint-Ferreol, Rhône d'Ulmet, and Bras de Fer separate bordering depressions from the heart of the delta. The outline of the Vaccarès has been established on all sides except the south by natural levees. Sea cliffs cut into the levees are between 1.0 and 1.7 meters high at most places. Their faces are fresh but the material sapped by the action of small waves along their bases is not readily transported to the central part of the étang and so accumulates to form a marginal protective beach. In driving back its bounding levees the Vaccarès has formed a long shallow fetch for

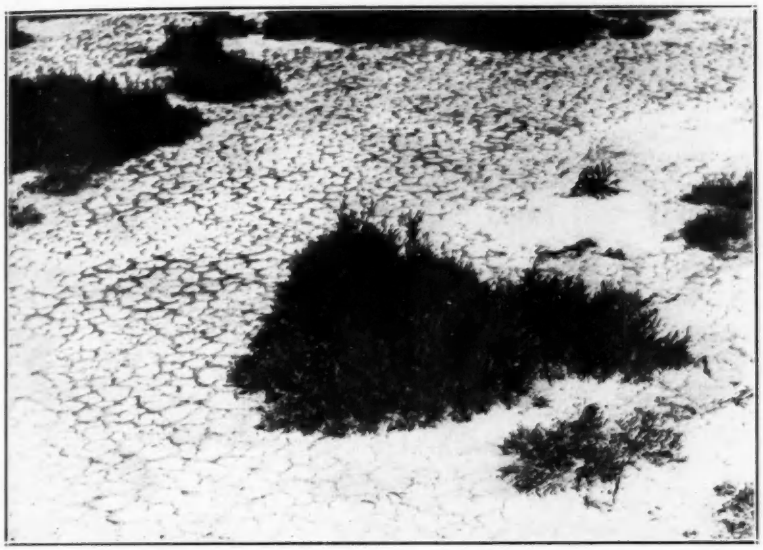

FIG. 30.—Detail of mud-cracked, Salicorn covered, surface of a sansourie in Île du Plan du Bourg.

the dissipation of translatory energy. Only under the waves of severe storms is sea cliff retreat taking place to any considerable degree today. No particular shore seems to exhibit any advantage over any other in this regard. Figure 18 shows a typical sea cliff on the eastern side of the étang and Fig. 20 one on the western. Equally fresh cliffs occur along Saint-Ferreol levees north of the étang.

Étang de Vaccarès is slightly over a meter deep today (*99–77*). Seepage, drainage from ditches, and rainfall fill it. Evaporation, especially during the mistral, lowers it. Shifts in wind direction distort the water surface, laying bare several miles of bottom on one side and bringing water up toward, or even to, the sea cliffs on the opposite shore.

South of Étang de Vaccarès are scores of irregular islands separated by mazes of narrow channels and minor étangs, many of which bear individual names. This "Baises de baisso" region owes its surficial complexity to the subsidence of an extensive marsh whose surface contained faint traces of old crevasse and shore deposits. The exclusion of sea water from this region by the "dike against the sea" has converted wide areas of shallow étang into saline flat (Fig. 31).

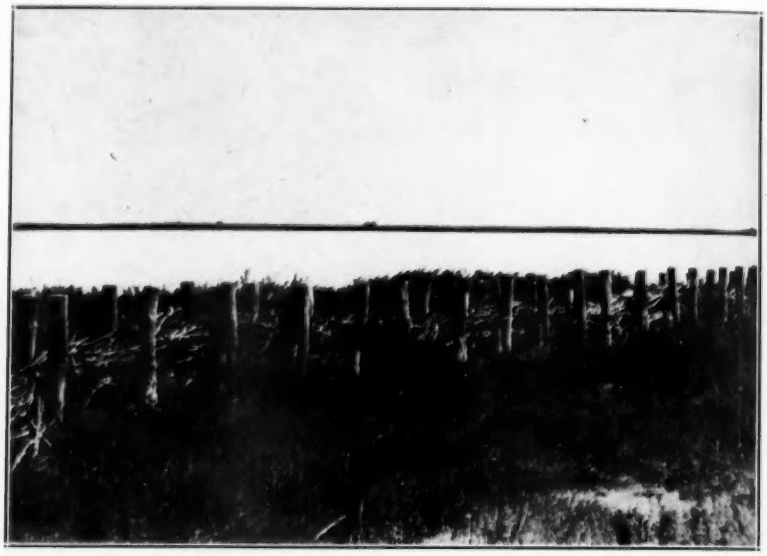

FIG. 31.—Saline flat on the inner side of the dike against the sea south of Étang dit l'Impérial, about four kilometers northeast of les Saintes-Maries. The main dike is an earth ridge slightly over a meter high and just wide enough to carry a narrow road on its crest. The parallel post and brush structure shown is a breakwater on the inner side of the dike. The dike is located two or more kilometers from the shore at most places and is rarely as close as one-half kilometer.

Bois des Rièges is the best preserved old shore line of the lower Camargue. Its sandy surface nowhere attains an elevation of over two meters. Its 360 hectare area is distributed in an elongate manner parallel to the northern shore of Golfe des Saintes-Maries and about five kilometers inland. Here grow Phœnician junipers from six to eight meters high, *Phillyrea angustifolia, P. media, Rhamus alternus, Tamarix gallica, Ruscus aculeatus, Rosmarinus officianalis, Clematis flammula, Cistus salviæ folius, Smilax aspera,* and *Daphne gnidium* (88–39). For the Camargue this is an unique floral display but it occurs again, under similar edaphic conditions, in the Petite Camargue, where also grow pins pignons, some 18 meters tall. Low recent dunes along the coast are being fixed by invasions of *Salicornia macrostachya, Argopyrum junceum, Ammophila areanria* (Gourbet), and *Crucianella maritima.*

The plaines d'enganes and gazes south of Vaccarès continue westward into the territory north of les Saintes-Maries, but here they lie in a pattern

of definitely oriented regional grain caused chiefly by crevasse deposits leading down the natural levees of Rhône de Saint-Ferreol. Baisses de Saxi, Étang de Consécanière, Étang de Ginès, and Étang des Launes display the pattern, all being elongate with longest axes bearing about north-north-westward. The alluvial ridges between them are slightly higher than their bordering marshes.

North of Pont des Cinq Gorges the natural levees of Rhône de Saint-Ferreol are high enough to block drainage into the Vaccarès and northwest of them are conspicuous basins between crevasse ridges from the Silvéréal and Albaron channels. The largest of these is Marais de la Grand Mar, north of the Vaccarès. Though prosperous farms occur along the natural levees both to the north and south of this basin and the Marais was drained prior to 1870 (33–431), it is practically uninhabited today and only of minor use as pasture.

Pâtis de Gouyère, Pâtis de la Trinité, Marais des Brans, and Marais de la Sigoulette are the principal basins between Silvéréal and Saint-Ferreol natural levees. A well-planned system of canals and drailles conducts surplus waters eastward to Étang de Vaccarès. Roubines are canalized channels used for irrigation. In this district they head along the Petit Rhône and flow along the crests of crevasse ridges between basins. The more prosperous farms are located on crevasse deposits and each is likely to have a roubine of its own, with its fields located on either side of the channel. Surplus waters eventually reach the basins, whence they are drained through canals and drailles. Sluggish drainage ditches bear the name égout, a name used more commonly on the eastern side of the Vaccarès than elsewhere. An égout, draille, or canal is ordinarily wholly artificial in origin but a roubine may always be suspected of natural origin. Roads and trails seek the higher ground along roubines, not the levadons along a draille or an égout.

North of Île du Plan du Bourg are numerous small basins between the Grand Rhône and Rhône d'Ulmet natural levees. Their shapes are influenced notably by the sinuosities in the pattern of the latter stream and their elevations are lowest westward. Marais de Grenouillet (MT in Fig. 12) is an excellent example. Alluviation has erased most of the étangs originally existing anywhere to the east of the d'Ulmet channel, the few small bodies of water remaining being concentrated toward the west.

West of Bras de Fer the low areas between minor crevasse deposits contain much wet marsh and numerous small étangs. Toward the south are patterns of land and water distribution originated by the advance of Bras de Fer into the Mediterranean. The larger étangs are essentially parts of the original water surface between advancing distributaries. Westward,

along the coast toward les Saintes-Maries, are many topographic results of southward coastal advance. Rather elongate lagoons between sandy strips date from the comparatively recent time that Bras de Fer and Saint-Ferreol channels furnished enough sediment locally to build the coast outward.

Along the natural levees of the Grand Rhône are pines (pins d'Alep, pins pignons), cypress, elms, poplars, and live oaks. The minstral has bowed many of the larger trees, especially the cypress and oaks, so that their crowns point southward. Willows line the immediate banks of the channel and also grow in the marginal parts of the basins. Tamarisks occur along levadons and on sandy strips toward the coast. False indigo, *Amorpha fructicosa*, has been introduced from America to fix dune positions and is succeeding quite well. It seems to thrive, for it has spread widely along banks of canals and natural channels.

COAST

The coast of the Rhône delta and adjacent deltaic plains displays a contest characteristic of deltas everywhere. The tendency toward shore advance in response to alluviation is opposed by the tendency toward retreat under the attack of waves. Slow subsidence favors coastal retreat, but the effect is by no means as pronounced as in the case of larger deltas.

In broadest outline, the coast consists of four segments so arranged that one fundamental pattern occurs twice. Along two east-west segments the coast is in retreat. Along two north-south segments it is advancing into the sea.

The Petit Rhône now discharges about midway along an east-west coast about 34 kilometers long. On the west the coastal segment is terminated at Pointe de l'Espiguette, where a smooth bend leads to a north-south coast about seven kilometers long. The Grand Rhône discharges toward the eastern end of an east-west coast about 27 kilometers long, which is terminated on the west at Pointe de Beauduc, where a gentle bend leads to a north-south segment about nine kilometers long. To the west of Pointe de l'Espiguette is the Golfe des Aigues-Mortes and to the west of Pointe de Beauduc is the Golfe des Saintes-Maries, or of Beauduc. East of the delta, between the easternmost pass of the Grand Rhône and the rocky coast leading to Cap Couronne is the Golfe de Fos. West of the delta is the bar-fringed coast of Languedoc.

Behind the active shore lines, to a maximum distance of 15 kilometers inland, are the beaches of geologic yesterday. These are sandy belts rising slightly above surrounding étangs or marshes. They are best developed on the deltaic plain west of the Silvéréal channel, but traces occur in the Petite Camargue and in the southernmost Camargue. One small but very

significant old beach, Île de Lansac, occurs east of the Grand Rhône. These old beaches are exactly similar to the cheniers of southwestern Louisiana and are referred to as cheniers in this report.

Advancing Shores

The two north-south shores of the delta are advancing, most conspicuously near their terminal capes, de l'Espiguette and de Beauduc. There is also advance of shores in the immediate vicinities of each of the two active branches of the Rhône. Elsewhere the shores are retreating into the land.

The rate of advance of Pointe de l'Espiguette is ordinarily considered as about 10 meters per year (99–210). A lighthouse on Terre Neuve, north of the cape, stood 40 meters from the shore line in 1869, 159 meters in 1874, and recent maps show it about 550 meters inland. It is chiefly over the last century that observations show an advance of about 1,000 meters (79–55). There is danger in accepting extrapolations from such figures.

Pointe de Beauduc advanced an average of 30 meters per year between 1760 and 1840, 17 meters per year since then (99–210). Such rates are certainly much lower than those obtaining between the 15th and 18th centuries, when the deposit of Bras de Fer was concentrated toward the point (16–203). The projection of Pointe de Beauduc westward is greatly pronounced in comparison with that of de l'Espiguette, a fact almost certainly related to the greater modernity of Bras de Fer than of Silvéréal distributaries. Since 1711 Grand Rhône depositional activities have been directed eastward, toward Golfe de Fos.

Practically every estimate in literature concerning the advance of land in the immediate vicinity of the mouth of the Grand Rhône is based upon studies made about a century ago by Surrell, who found that the advance was 55 meters per year between 1700 and 1710, decreasing to 45 meters per year between 1767 and 1775, and to 35 meters per year between 1830 and 1840 (105–319). Barré (7–356) gives an average rate of 50 meters per year and Blanchard (16–204) as 40. Commonly such values as 26 kilometers in 22 centuries are given (79–44), or an average of "1 lieue per century." These follow de Beaumont (87–211) and are unreliable extrapolations of rates taken from Bras de Fer and St. Louis channels.

Changes in Area

The advance of any individual channel has little meaning from the standpoint of coastal advance as a whole. Where advance is actually across a coastal marsh it may be about as rapid as water flows. In the general process of coastal advance the only relevant consideration is how far the strand has actually moved from former limits. Natural levees may push

forward very rapidly at times but such spurts seldom last for more than a few decades. The building of adjacent coasts along marshy or low belts between passes may be quite slow. The salient natural levee is ordinarily driven back by wave attack in a comparatively short time after abandonment of the channel that formed it. Losses are just as important as gains with regard to shoreline positions but the extrapolators who give us our long term estimates of coastal advance rarely include them in their calculations.

Estimates as to the area of land added to the Rhône or any other delta during long terms of years are practically worthless. The popular figure of 250 to 300 square miles since 1737 (71–225) is almost certainly based upon comparisons of charts in the immediate vicinity of the St. Louis channel and fails to take into account losses elsewhere. Between 80 and 120 square miles since the Gallo-Roman period is another guess based upon cartographic studies (98–102). The older maps are by no means accurate enough to justify such a detailed conclusion. Repelin estimated 250 to 400 square kilometers of additional surface during the last 2,000 years, stating that this is all the land south of latitude 43° 26′ N (99–65). The latitude mentioned is that of Grand Passon, which leads to the conclusion that he regarded the addition as the depositional product of Bras de Fer and the St. Louis channel. Unfortunately for the calculation, he did not realize that the older Rhône d'Ulmet, below Grand Passon, along Marais de l'Escale to the vicinity of Étang de Faraman, built most of this land before the start of the period considered. There is no factual basis for believing that during the last 20 centuries the delta has either gained or lost in area.

Cartographic approaches to the question of gain or loss in delta surface are valid only when based upon the accurate charts of the last few decades. Extrapolation of results from such short bases is wholly unwarranted, for the reason that accretion is something that goes on by fits and starts. Immediately after some striking change in channel patterns occurs, the addition of delta surface may be enormously rapid, declining in rate to comparative insignificance in the course of a few decades. Though steadier and more positive in action, the processes of land loss, chiefly wave attack and subsidence, go on at far from uniform rates.

Retreating Shores

The long east-west segments of the coast of the Rhône delta are in retreat before wave attack. Values for the rate of retreat are based chiefly upon information from two localities, the vicinity of the lighthouse at Faraman on the more southerly coast, and that of les Saintes-Maries, on the northerly of the two east-west segments. It has long been recognized that these coasts are retreating (98–103).

The rate of retreat near les Saintes-Maries has been stated as 250 meters

in 50 years (79–56), and also as double that rate, or an average of 10 meters per year (99–210). The factual basis for such estimates appears to be the commonly accepted statement that during the reign of Charles II, Compte of Provence, land extended south of the church for a distance of half a league (51–11). The distance between church and shore today is about two city blocks, so nearly all of the half-league is now gone, the loss dating from the latter part of the 13th century. Cartographic evidence confirms the conclusion in that it shows the disappearance of Île d'Orgon, in about 1820 (99–68). Surrell states that the actual retreat of the coast started in about 1531 and George correctly attributes it to the abandonment of the Saint-Ferreol channel (51–11).

Retreat of the shores near Faraman is well authenticated by measurements. The original Faraman light was 450 meters from the shore in 1837 and only 70 meters in 1872 (104–66). The beacon of Beauduc stood 600 meters inland in 1841 and only 40 meters in 1872. Average rates of retreat have been stated as 40 meters per year between 1710 and 1760, 30 meters per year between 1760 and 1836, 15 meters per year since then (99–210). Since 1706 the total recession has been over 4.5 kilometers. The volumetric loss has been calculated as 400,000,000 cubic meters in 200 years, or 200,000 per year (99–68).

Wave action has exposed a tough bluish clay near Faraman and this is supposed to have slowed down the rate of shore retreat (91–79). Knobs of clay, flat pebbles, shells and artifacts were thrown upon the beach at les Saintes-Maries during heavy storms in 1926 and 1927. There is a decided tendency expressed in literature to regard the clay as something much older than modern deposits. Exactly similar materials on the retreating Chandeleur Islands of the Mississippi River delta are known to be less than a thousand years old (106–62), for they contain Indian artifacts representing a culture relatively late in the coastal Louisiana Indian chronology. The bluish clay with which they are associated is one of the latest and youngest beds in the delta. Similar deposits occur elsewhere (5–252; 125–215). In the case of the Rhône delta there is no real evidence that the bluish clay near Faraman is materially older than any other deposit at similar depths below the surface. The pebbles near les Saintes-Maries are probably derived from cheniers and are similar to those reported along the coast to the west. The fact that some of them have been cemented together is not particularly significant from the age standpoint. This is the ordinary condition of recent marine gravels along the northern Mediterranean coast. The retreat of the Faraman coast is essentially taking place at the expense of Rhône d'Ulmet and later deposits. All of these are modern in the geological sense.

Cheniers

Though evidence is inconclusive with regard to increase or decrease in area of the deltaic plain of the Rhône, it is clear that rearrangements in delta outlines have taken place during modern times and some of these involve areas of considerable size. The history of channel succession demands this conclusion and patterns of abandoned shores confirm it. While the total area of the plain may have remained about the same during the last fifty or more centuries such a result has been accomplished only through the balance between coastal advance at some places and retreat elsewhere. As a general principle, advance has taken place near the mouths of active channels and along coasts favored by deposition from littoral currents. On other coasts the shore is driven back into the land by waves.

In driving a shore inland waves carry fine material seaward. Coarse material is thrown landward and forms a beach. The beach marches inland, with retreat of the shore, and in doing so gains in volume. The bulk of the coarse material on the Rhône delta is sand, and sandy beaches characterize most of the coast. Shells and shell fragments exist in abundance. It has been estimated that low dunes along the coast consist of from 60% to 70% of sand, chiefly quartz, the remainder being chiefly shell fragments (79–52). In some places, especially along the shores north and west of the Golfe des Aigues-Mortes, there is some admixed gravel.

While an efficient mechanism exists for driving a beach inland, there is no corresponding means for moving it back, into the sea, or to keep it on the shore of an advancing coast. If a shore retreats for a period sufficiently long to establish a good beach with smooth outline and later has some reason to advance, the beach cannot follow it out. It remains stranded behind the new deposits. In this condition it is called a chenier (108). If the history of some particular coast involves several fairly long periods of alternating retreat and advance during modern times, and if the net result has been that of advance, a group of stranded beaches, or a chenier series, may be left in the marshes behind the latest shore. This appears to be the case on most deltas.

Deltas are favored for chenier development more than other parts of a coast because they supply exactly the conditions requisite for alternations between shoreline advance and retreat. Channel mouths rarely remain in one position for more than a few centuries. As they shift, areas of coastal advance shift with them and abandoned areas of advance become areas of retreat.

Cheniers are rather permanent features. They are readily recognized because there is ordinarily a striking contrast between the coarseness of

their materials and the fineness of those on either side. Silt or clay is the normal material of marshes both to the front and the rear of a chenier, whereas the ridge itself is normally sandy and contains fragments of shells or other marine organisms, such as one finds along a modern beach anywhere. A chenier may be destroyed by the advance of the sea across its surface or hidden by subsidence and burial beneath younger deposits. It is not likely to be buried by alluvium where subsidence is wanting. The main chenier series of the Mississippi River deltaic coastal plain occurs well to the west of the existing mouths of the river. Followed eastward individual cheniers dip under the surface of the marshes. This is reasonable proof that the river mouth region is subsiding more rapidly than is the area farther away. Exactly the same pattern characterizes the Rhône.

The main chenier series of the Rhône delta occurs on the deltaic plain west of the Silvéréal channel. A few cheniers extend toward the Grand Rhône far enough to reach the western and southwestern parts of the Camargue. They are absent in the vicinities of Rhône d'Ulmet, Bras de Fer, and the existing Grand Rhône channel. One appears east of the Grand Rhône.

As many as eight old shores, or cheniers, have been reported on the Rhône deltaic plain (7–356). The most inland and therefore oldest has been described as extending from near the eastern end of Étang de Mauguio eastward north of Aigues-Mortes, across the southern side of Étang de Vaccarès, toward Fos. Barré considers this the best abandoned shore of the entire delta, and describes two others which are quite complete. Charles Martins found three old shores near Aigues-Mortes, all of which contained shells that also occur on the active beach a few kilometers to the south (27–360). He noted the presence of étang deposits between the sandy belts.

The cheniers as mapped by Charles Martins in 1874 (79–48) are shown in Fig. 16. The writer has checked them in the field and agrees thoroughly with Martins' identification. They were described as follows:

I. A dune belt extending 22 kilometers E-W, about 15 kilometers from the sea, passing through Silvéréal. Gravels are comparatively common in this belt.

II. "Chemin de la Pataquière," the old route to Montpellier, extends from Chaumont eastward, past the northern side of Aigues-Mortes to Poste de la Larbière, near the northern end of Étang de l'Arameau. Gravels occur toward the western end of this belt.

III. A belt tending to approximate the configuration of the existing coast from the southeastern end of Étang de Mauguio through the salins between Aigues-Mortes and Grau-du-Roi, along the north-

ern side of Rhône-mort, and eastward to the lower end of Étang de l'Arameau. No gravels are known in this belt.

As Martins uses de Beaumont's term "cordon littoral" for both cheniers and the active beach, he describes a fourth belt, the existing beach, with a continuation, "Boucanet," behind Terre-Neuve, of Pointe de l'Espiguette. Gravels occur toward de Mauguio. In grouping together the several ridges of dunes and broad sand flats of Pointe de l'Espiguette, Martins clearly indicates his understanding of the contrast between the latest, active beach complex and the cheniers associated with earlier shore lines.

The shells found in the oldest chenier include: *Cardium tuberculatum*, L., *C. edule*, L., *Pectunculus glycimeris*, Lam., *Cytheræa chione*, Lam., *Mactra stultorum*, L., *Natica olla*, M. de Serres, *Cerithium vulgatum*, L., *Solen strigulatis*, L., *Murex brandaris*, L., and *Ostrea*. This near-shore fauna, though containing brackish water elements, is quite different from that found in the étangs of the Camargue and is exactly that found along existing beaches. It certainly demonstrates the marine origin of the chenier, but this fact is so evident otherwise that it hardly seems necessary to substantiate it.

The most inland chenier exhibits clearest topographic development today. Parts of it have been called de Pinéde and Silve Godesque (79–54). In places it retains remnant dunes three to four meters in height. Though cultivation, chiefly of the vine, has subdued much of its topography and modified its original vegetation, scattering parts are essentially in their pristine condition, supporting pignon pines, oaks, and white poplars (Fig. 32). Near Montcalm, not far west of Silvéréal, where the chenier is relatively low, the vegetation includes: *Phillyrea angustifolia, Cratægus monogyna, Rhamnus alaternus, Daphne gnidium, Clematis flammula, Rubia peregrina, Lonicera etrusca, Pistacia lentiscus, Quercus pubescens*, and *Pteris aquilina* (88–37). Patches of this flora occur east of the Petit Rhône for a short distance. For this long, continuous, sandy belt the writer proposes the scientific name Chenier Godesque, after Sylve Godesque, one of its best known parts (Fig. 16).

It has been assumed generally that the Silvéréal channel contributed the bulk of the material constituting Pointe de l'Espiguette and the chenier series behind it (16–203; 79–56; 98–106). Strictly speaking this is not the case. The chenier series was formed earlier than the Silvéréal channel, or other Rhône course whose trace remains today on the surface. The Tourradons channel was forced to follow the lowland north of Chenier Godesque for a great distance westward. Had not the chenier antedated it, it is reasonable to believe that the Rhône would have found its way to the sea before reaching the vicinity of Étang de Mauguio. The alternate hy-

FIG. 32.—Chenier Godesque near Trouchard, north of Aigues-Mortes. Pignon pines mark the sandy soils of this region and as a rule identify the positions of cheniers.

pothesis that the shore worked its way back to general parallelism with the channel is too unlikely to merit consideration. The northwestward trends of Silvéréal branches were certainly determined by preëxisting chenier trends. The fact that Rhône aux Tombes cuts across the third chenier proves the presence of that chenier at the time when one of the oldest Silvéréal courses was active.

The bulk of the land behind Pointe de l'Espiguette was formed through a complicated history of alternate advances and retreats of the shore that took place before either the Tourradons or Silvéréal channels were formed. Only Terre-Neuve, seaward from any of the cheniers, has been formed during and since Silvéréal times.

Writers who have assumed that the Silvéréal channel contributed the bulk of land on and to the rear of Pointe de L'Espiguette have estimated that the point will cross the Golfe des Aigues-Mortes and advance to the vicinity of Palavas in 18 (79–56) or 20 (98–106) centuries. The remnant gulf will be left as an étang under this idea. From any standpoint the element of time has been grossly underestimated in such calculations. Values for the advance of the point within recent years are adopted in such extra-

polations without justification for the action. It is assumed that the point will advance as rapidly as sediment displaces the water ahead of it. This idea is fallacious. In order to actually displace a cubic foot of water ten cubic feet of sediment may have to be pushed down isostatically by the weight of the material deposited. It is also likely that upsets in channel pattern will occur before 18 or 20 centuries have elapsed and these may well change the shores under consideration from an advancing to a retreating condition.

Bois des Rièges, in the central part of the lower Camargue, has been interpreted in several ways. Denizet (33–426) regards the surface as dominated by shore dunes and hence considers it as an old shore line. George (51–9) doubts this interpretation for the reason that many of the dunes are isolated and present an appearance not typical of existing shores. Oldham (91–61) accepts the old shore hypothesis. Repelin (99–55) not only accepts the hypothesis but traces the shore from the vicinity of Radeau Redouière eastward to that of la Roque. While Repelin is probably too ready to accept various crevasse deposits and other features as evidence of old shore positions, there should be no serious doubt about his general conclusion with regard to Bois des Rièges. It has every characteristic of an old chenier. Its height and position suggest that it is an intermediate remnant of the shore represented by Chenier Godesque, on the west, and Île de Lansac, on the east.

Île de Lansac is an extremely interesting chenier about two kilometers north and slightly west of la Roque, near Galéjon. Whether it is the eastward extension of Chenier Godesque, as the writer suspects, or an entirely different shore line, matters but little. It is a narrow sandy belt supporting Phœnician junipers and smaller plants typical of cheniers to the west. The significant point about its location is its position a considerable distance from any modern equivalent of the Grand Rhône, in a place where subsidence under load should be much slower than that in the Camargue.

Blanchard (16–205), Repelin (99–56), and the great majority of earlier writers identified most of the east-west natural levee and crevasse deposits as old shore lines. This notion is most perfectly expressed with regard to the levees of Rhône d'Albaron. Blanchard disregards geographic continuity in identifying Albaron levees as the eastward extension of Chenier Godesque, so that one long shore line is postulated as having extended from near Aigues-Mortes to Mas Thibert, on the edge of the Crau. Repelin not only considered Rhône d'Albaron levees as a shore line but also identified many crevasse deposits as such, *e.g.*, near Grand Mas d'Avignon and near Mazet du Cassaire. Sequential channel history clearly disposes of such views.

The chenier series of the Rhône deltaic plain reveals a slight subsidence of land toward delta margins and more active subsidence near the Grand Rhône and more central parts of the Camargue. Slight subsidence toward Aigues-Mortes is indicated by the occurrence of marine shells only at levels lower than those where they now occur along active beaches. The general absence of cheniers in the Camargue, except for Bois des Rièges and a few traces of sandy strips toward the west, coupled with their appearance on either side, is clearly suggestive of more active subsidence centrally in the delta. The conclusion of de Cossigny (27–360) that étang deposits between cheniers near Aigues-Mortes indicate an uplift of the deltaic plain is unsupported by valid observation or argument.

Offshore Features

Golfe de Lion is the name applied to the northwestern corner of the Mediterranean, between Cap de Creus and Toulon. Much of its coast is rocky, headlands being formed on outcrops of Miocene basalts, toward the west, Middle Jurassic sedimentary rocks at Séte and elsewhere, Upper Cretaceous limestones east of Fos and along coastal Nerthe, Lower Cretaceous, Jurassic, and other sedimentary and igneous rocks east of Marseille. To some degree these same rocks are found on bottoms, out from the shore.

Soundings in the western part of Golfe de Lion by Pruvot and Thoulet indicate gentle slopes at most places. Two rechs, submarine valleys, one near Cap de Creus and the other heading at Roches du Fontaindrau, not far to the northeast (124) have been cut below ordinary bottom levels. Depths in excess of 700 meters were found in the rechs, and drags brought up fragments of schist resembling those of coastal mountains (124–474).

The smoothly sloping bottom of the northern part of Golfe de Lion has been identified as continental shelf by several writers (53–352). Some picture it as essentially structural in origin (7–348). The Rhône delta is supposed to have advanced as a thin veneer over a platform of Mesozoic rocks (16–201; 99–288). Outcrops of Cretaceous rock at Arles and la Roque d'Odor are cited in support of such notions. The advancing front of Rhône sediments is supposed to have pushed the Mediterranean shore southward before it. These are rather conventional views concerning deltas anywhere. Blanchard has pointed out the similarity between deltas of the Rhône and Nile in conforming to them. As a matter of fact these ideas rest on most uncertain evidence, much of which is pure assumption. Where, for example, is the landward continuation of the Mesozoic platform? What subsurface evidence supports such ideas? Do the finds of a few schist fragments in submarine valleys establish a rock platform? When it is realized that the whole Rhône delta region is one of geologic

complexity inland, is it not absurd to regard simplicity in isobaths as evidence of underlying simplicity in geologic structure?

A map of bottom deposits shows well defined bands of sediment, with "sand" (defined as material 95% or more sand) toward the shore and "silty ooze" (10% to 95% sand), and "ooze" (less than 10% sand) in successive belts outward (53–353). Excepting the vicinity of capes and local gulfs, the sand belt is about six kilometers wide and extends to depths of about 40 meters.

The two east-west segments of delta coast are flanked by benches of relatively shallow water fronted by steep slopes into the gulf. At Faraman the case appears clear that the shallow water represents the extent to which the coast has been driven back since 1711 (99–66). The duplicate feature near les Saintes-Maries has been regarded as growing "talus de déjection" of the Petit Rhône (117–1190), but the correctness of this interpretation is unlikely. Mud bottom in the vicinity and large blocks of mud cast upon the beach in times of storm indicate rapid erosion on the bottom and shore retreat certainly is taking place at the expense of deposits other than those the Petit Rhône has carried during the past few centuries. Similar materials at Faraman have been called "blue clay" and regarded as proof that the shore is eroding "older alluvium." In each case the deposits appear to be materials that have accumulated under marsh conditions, in an environment similar to that of the gazes of the lower Camargue. Their consolidation into material sufficiently coherent to be cast as blocks upon the beach is by no means proof of any considerable antiquity. Similar blocks characterize outer shores of the retreating parts of the Mississippi River delta (106–62). Their presence is a reliable indication of shore retreat.

Sand bottoms predominate in the vicinity of the advancing coasts of the Rhône delta. The sands contain an abundance of shells (117–1191). These coarse materials are the winnowed residues of deposits that are accumulating today under the prevailingly easterly currents generated by southeast winds along the coast west of Marseille (79–54). They occur most conspicuously on bottoms flanking the advancing points and along nearby north-south coastal segments.

It is an interesting fact that both of the main active branches of the Rhône lead to retreating coasts. This paradoxical feature is to be related chiefly to the recency of these channels of artificial origin. As a matter of fact the Petit Rhône has advanced the coast slightly at Grau d'Orgon and the Grand Rhône has largely succeeded in silting up the Golfe de Fos (98–103).

While most writers have associated the advance of Pointe de l'Espiguette with the Petit Rhône and that of Pointe de Beauduc with the Grand Rhône,

such statements are only part truths. The advance of the two points is to be related chiefly to the abundance of material supplied by the retreating coasts lying just up-current from each of them. Sediment carried down the active channels must be regarded as of secondary importance. The coast of Faraman alone loses over twice as much material per year as the whole Rhône transports (22–216; 99–68).

Changes of Level

Shores in the vicinity of the Rhône delta offer little support for the notion that the "traditional classification of shore lines" has any usefulness. Just to the east, along the coast of Nerthe, is a remarkable display of characteristics of submergence. The calanques of this region, drowned valleys with white walls standing sheer above deep blue waters, are scenic gems of submergence. Numerous stacks and small islands indicate an instability of shore lines such as submergence most readily produces. Cliffs in the vicinity of Marseille have retreated 820 feet since the days of Cæsar (98–124). Immediately west of the delta, along the coast of Languedoc, are some of the longest and most perfectly developed offshore bars on the Mediterranean. Distance to the five-fathom line is a matter of from two to three kilometers along this coast. Coastal lagoons occur almost continuously behind the offshore bars. They need few inlets from the sea because tidal ranges rarely exceed 16 inches and reversals in wind direction seldom change sea-level more than five feet in this vicinity. The coast is so smooth for a distance of somewhat more than 160 kilometers that, in the modern sense, it is practically harborless. Here are the most commonly cited characteristics of shore lines of emergence. Between the smooth coast of Languedoc and the rock-bound coast east of Fos lies the "neutral" coast of the Rhône delta.

If the principles embodied in the traditional classification of shore lines be applied to the vicinity of the Rhône delta, they lead to the conclusion that the delta happens to be an axis between a region of rising coasts to the west and sinking coasts to the east. No support of this conclusion is to be found in landforms inland from the coasts in question. Pleistocene terraces fail to reveal traces of such diastrophic warping. All lower courses of streams reveal drowning, the universal and inevitable consequence of large-scale Recent recession of continental ice-caps.

A commonly held view that the Mediterranean recently extended as far inland as Arles, the delta front having been driven outward as a thin deposit of deltaic sediment accumulated over a bedrock platform (99–55), is supported by no factual evidence. Subsurface evidence indicates a much greater depth of Recent sediment than is ordinarily suspected. Except-

ing places where local downwarping has thickened the Recent section, the depth of alluvium appears to be equal to the amount that Recent seas have risen in level as the result of glacial wane.

There may be a question whether the Mediterranean oscillations in Quaternary sea-levels followed precisely those of the ocean systems. The Strait of Gibraltar is today sufficiently deep to reach commonly accepted levels of glacial seas (69–171; 101). If Pleistocene depths were less in the Strait the Mediterranean may have sunk to levels much below those of the Atlantic (30–441; 127–449). Many believe such was the case, owing to high evaporation rates in proportion to inflow. In any event the possibility of a Mediterranean level above the Atlantic is hardly worth entertaining. Theory and observational fact seem to agree that the depth of Recent sediment in the Rhône delta is at least equal to the Recent rise in universal sea-level. Such was probably the case during earlier Quaternary interglacial rises as well.

The low level pre-Recent sea must have established a shore at least 20 kilometers south of the existing shore of the Rhône delta. Charts indicate a rather distinct bench slightly less than 100 meters deep south of the delta. This may well be the deltaic coastal plain established during Wisconsin time. It is likely underlain by alluvial deposits and these may have considerable thickness.

The sea has embayed coasts, such as those of Nerthe, on all steep and rocky shores of the Mediterranean. Where it flanks gentle slopes, with an abundant sand supply, as along coastal Languedoc, it has smooth shores, along which waves have constructed offshore bars. Near large rivers abundantly supplied with sediment coasts reflect the contest between alluvial advance and wave attack retreat.

Disregarding subsidence resulting from load and considering only submergence caused by rising sea-levels, the conclusion seems inescapable that deltas formed near valley mouths, possessing sufficient virility to prevent their valleys from becoming estuarine, must have a thickness of Recent deposits at least equal to the change of level involved. Accepting such values as Antevs, Daly, and others have estimated for the last major rise in sea-level, we must picture the pre-Recent flood plains as lying at least 200, and probably 300, feet lower than those of today. In the main these old flats are now covered with layer after layer of alluvium. If we could establish by means of an intensive campaign of bore-holes the patterns and positions of various delta channels of the many levels between earliest and latest Recent times they would resemble the veins and ribs in a pile of leaves, only the top leaf representing the modern surface.

With rising seas it is reasonable to believe that the delta front ordinarily

retreats shoreward, along with other parts of the coast. Only an excessive amount of alluviation could build a delta so that its shore advances relative to the general coast. This condition may obtain on some deltas. In the case of the Rhône it appears that there has been no such surplus of sediment. The low-level delta of Wisconsin age reached farther south than does the delta today. Its distal parts may completely escape burial by significant quantities of Recent deltaic materials.

Summary on Delta Area

Within historic time, locally meaning back at least to the 5th century, B.C., there has been no great change in the area of the Rhône delta. Some shores have advanced as much as two kilometers, as in the case of Terre-Neuve, while others have retreated notable amounts, as south of les Saintes-Maries. The volume of sediment gained on one hand may have no more than offset the loss on the other. It is interesting to note that the traces of pre-historic channels extend to the present coast in most cases, and, in all probability, originally went beyond. The mouth of Rhône d'Ulmet was located at least as far south as Salin de Giraud. Various Silvéréal mouths were located at least in the vicinity of today's coast. Tourradons extended across nearly the whole deltaic plain to the west. Rhône de Saint-Ferreol undoubtedly extended a considerable distance beyond the existing coast of Golfe des Saintes-Maries. It is impossible to support a thesis of rapid delta enlargement during recent centuries in light of these facts.

Charles Martins says that Gallia Christiana, published in 1656 by Guillaume de Castel and Pierre d'Andoque, has misled historians badly in regard to shoreline advance (79–56). This work contends that Aigues-Mortes was on the sea in 1248. Rings for docking boats along the ramparts were actually used by small craft plying Étang de la Ville, not by vessels used in transporting knights across the Mediterranean. Early statutes of Aigues-Mortes name the étangs between the city and the sea and the list is exactly that of today. The canal to Grau du Roi was started during the reign of Louis XV and named in his honor. Almost no change has occurred along the coast near its mouth since its construction.

Four or five times as many miles of coast are retreating today as are advancing in the vicinity of the Rhône delta. It seems reasonable to believe that such has always been the case. It is unfortunate that accurate maps are too new in the scheme of things to aid in a cartographic approach to the problem of net change taking place in delta area. Until strong evidence to the contrary appears, it is reasonable to believe that the delta has approximated its present area for many centuries. Certainly the common belief

that between 80 and 120 square miles increase in area has followed Gallo-Roman times (98–102) is erroneous, being based upon evidence of St. Louis channel behavior since 1711, with complete disregard of complexities involved in actual changes in total area, and without a clear picture of how the advance of the St. Louis channel itself occurred.

THICKNESS OF THE RECENT DEPOSIT

Adequate subsurface information is practically non-existent for forming conclusions regarding thickness of either Tertiary or Quaternary deposits in the Rhône delta region. Numerous water wells furnish information for very shallow depths, few having penetrated the section for more than 30 meters and none for over 150. No deep test well has ever been drilled. One familiar with subsurface conditions of the Mississippi River delta, with its tens of thousands of oil wells, scores of which attain depths in excess of 10,000 feet and several more than 13,000, feels severely handicapped in attempting to describe subsurface conditions of the Rhône delta.

Without the subsurface record of the Mississippi River delta it would be impossible, even with the most precise surficial data available, to estimate the thickness of either its Quaternary or Tertiary deposits. Probable values would be on the order of 5% of thickness actually existing. The best estimates as recently as 20 years ago were seldom over 10% of actuality.

Without the subsurface record, but with the best possible knowledge of surface geology, any rational estimate of the thickness of either the Tertiary or Quarternary section a geologist might make for the Rhône delta region would do well to attain 10% of the thickness actually to be revealed when deep borings are made. It is reasonable to believe that current ideas regarding thicknesses of the section are hopeless underestimates.

The one main compilation of thicknesses of Recent deposits in the Rhône delta is Picard's, "La Camargue." This work, published in Nîmes in 1901, apparently does not exist in the United States and it is unfortunate that the writer studied it with only moderate care while in France. Its data have been quoted many times and have been summarized by Baulig (8–501), whose subsurface contours on gravels are probably about as accurate as any that can be drawn on the basis of available information.

As early as 1851, de Roys (105–320) concluded that gravels underlying in the Plaine de Beaucaire at depths of from eight to ten meters reach a depth of 60 meters in the Camargue. His interest was that of computing the age of the delta. Using a 60,000 hectare area and the load of the Rhône as computed by Surrell, he reached the conclusion that the delta is at least 50 centuries old.

Modern writers, in general, have tended to recognize only very limited depths for the thickness of Recent alluvium. Baulig's views (8–502) are those generally held (50–5; 52–358; 67–99; 91–68; 99–74). Crau gravels are identified at 50 meters at Château du Listel, between Rhône-mort and Rhône de Saint Roman, 37 meters at Aigues-Mortes, 40 meters at Méjeanne, on Rhône de Saint-Ferreol, 40 meters at Giraud, 14 meters at the bridge near St. Gilles, and 23 meters at Gimeaux, in the High Camargue. The materials above these depths are chiefly fluviatile, with admixed peat at several places, and with a few intercalated "marine" beds. The latter are brackish étang deposits.

Denizot (34–41) emphasizes the presence of *Cardium edule* L., and *Paludestrina acuta* Drap., in various layers. Where blue mud containing these shells outcrops at elevations of 1.3 meters at les Saintes-Maries and about 1.0 meters on the shores of the Vaccarès, and at Combet, near Albaron, the beds are considered as truly "marine" (35–409; 36–354). The fact that these animals now live in various brackish étangs of the Camargue disposes of this notion. Including these "marine" beds, Denizot recognizes the Recent as about 30 meters thick (36–356).

It was the writer's good fortune to gain some valuable information from M. Moulias, of Trinquetaille, who has dug the majority of deeper wells in the Camargue during recent years. M. Moulias reported iron pyrite, marsh gas, hydrogen sulphide, and peat in nearly all wells. To such depths as 20 to 30 meters the vegetable material is relatively undecomposed. Below such depths the section is sandy and gravels are encountered where reported by Picard and Baulig. M. Moulias expressed great confidence in his ability to differentiate between Crau gravels and those belonging to the Recent alluvium of the Rhône. As a rule the latter are smaller and they are associated with fine black sand. His greatest disagreement with earlier conclusions is based on wells southeast of Étang de Vaccarès. At Fièlouse he found a thick sand section extending to depths well below Baulig's contours for Crau gravels and at Salin de Giraud a well 150 meters deep failed to encounter any gravels whatever. He interpreted the entire section as remaining in Recent alluvium.

There seems to be a strong probability that the thickness of Recent alluvium stated by Picard and Baulig is an underestimate. Though the Grand Rhône carries little or no gravel to its mouth today, lenticular gravels in the Camargue and the general increase in sandiness at a depth of 20 meters or more suggests that gravels were reaching the coast in considerable quantities earlier in the Recent stage. It would be a very natural mistake to confuse Recent and Crau gravels in well records, especially where the materials themselves have not been examined.

Baulig's map is a reasonable and conclusive representation in many ways, but it must be admitted that large areas lack adequate control. It must be recognized also that it was constructed in the light of a literature prejudiced in favor of the notion that Recent alluvium is very thin. Though there can be no weight to the argument that the presence of Cretaceous bedrock at Arles and Roque d'Odor indicates a thin section, the point has been made (16–21) and is taken seriously by most writers on the Rhône delta. With few exceptions, recent references to depth to Crau gravels in the Camargue are nothing more than reiterations of the opinions of Picard. Contradictory ideas have been disregarded, for example, the statement that gravel occurs at 37 meters in the deep well at Aigues-Mortes has been accepted as the depth to Crau materials, in preference to an older interpretation that nothing but Recent alluvial materials was encountered to the depth of 100 meters (98–102). If this conclusion, derived from the southwestern corner of the deltaic plain, is combined with the opinions of M. Moulias, that over 150 meters of Recent alluvium exists toward the southeastern corner of the plain, we have the not improbable result that the Recent alluvium of the delta extends to a depth considerably greater than that of the submarine flat at its front, which stands somewhat less than 100 meters below the Mediterranean.

The question of thickness of Tertiary section will not be discussed here, other than to say that no worth-while information exists today concerning it. Surface outcrops exhibit a small-scale reproduction of those in Louisiana. The deltaward tilting of Pleistocene terraces is exactly similar to that of Louisiana. By analogy we should conclude that it is likely that any estimate of thickness thus far made is probably on the order of 10% of the value a deep well toward the coast would demonstrate.

SUBSIDENCE

In comparison with the great delta of the Mississippi River, the Rhône delta exhibits only modest evidences of active subsidence. This fact will be interpreted on the basis of comparative loads of the two streams, by anyone willing to adopt the general theory that subsidence is directly caused by sedimentary loading (60–213). To an advocate of the opposed theory, that sedimentary loading occurs where subsidence is going on for some other reason, the balanced relationship must be impressive as a most fortunate chance. Whatever the cause of subsidence may be, its investigation should be divorced from theory and examined on the basis of factual observation.

Subsurface information is disappointingly inadequate for the Rhône delta. From it we gain only a suggestion that the Recent deposits probably

extend to depths below those of the submarine platform flanking the delta front. If more complete information is secured at a later date and this observation is confirmed, it may be regarded as evidence in favor of the theory that subsidence has resulted from loading.

Structural evidence in favor of delta subsidence is impressive. Both the Crau and the southern part of la Costière slope toward the delta and their gravels continue beneath its surface. The deformation of the Pleistocene has been such that the strikes of the terrace formations, from the Crau of Languedoc, on the west, past la Costière, to the Crau de Miramas, on the east, bend concentrically around the Recent alluvium and all dips are toward the center of heaviest loading (100). This deformation disappears up valleys and along the coast on either side of the delta. The dips toward the delta are altogether too steep to be initial dips. The terraces up all valleys conform quite closely to existing floodplain slopes. There has been a true downflexing toward the delta.

The oldest, uppermost terrace of the southern Costière drops from an

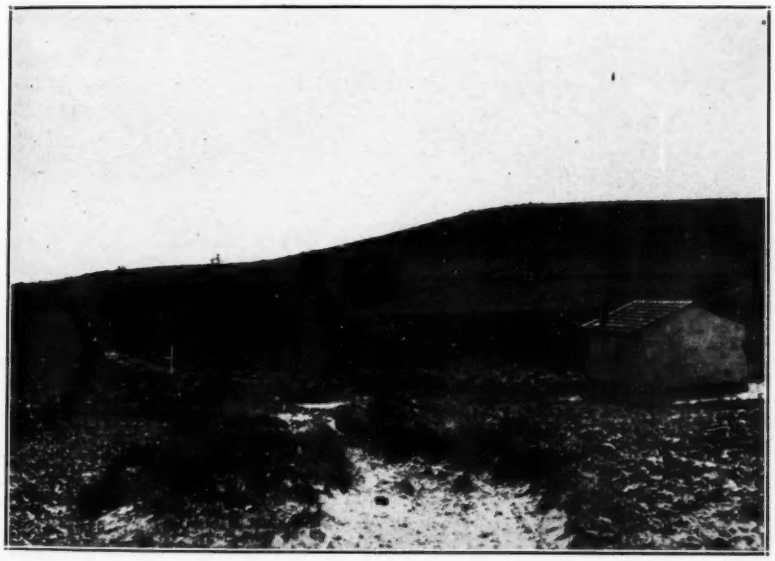

FIG. 33.—Scarp between the two higher terraces of la Costière, near Générac. The highest terrace, toward the right, will be shown in the next figures along a route leading southward to the coastal marsh. In this photograph the terrace elevation is 134 meters.

elevation of 134 meters, 1.5 kilometers northwest of Château de Surville, to marsh level at Franquevaux, seven kilometers away, the average gradient being 19 meters per kilometer. This surface may be followed without interruption from the vicinity of Gènèrac to Tour d'Anglas, near Pont des Tourradons. Figure 33 shows, on the sky line at the right, the truncated, inland, locally highest part of this oldest terrace. Its upper surface is true crau; an extensive gravel plain. Figure 34 shows the same gravels

FIG. 34.—Highest terrace, near Beauvoisin, showing gravels exposed in a pit, where the elevation is about 120 meters.

exposed in a pit about two kilometers southeast of Beauvoisin, where the elevation is about 120 meters. The surface is barren in its natural condition but much of it has been reclaimed and is in use as vineyard. Followed downslope this same surface reaches the marsh of the Stagna region at Franquevaux, Fig. 35. This settlement, together with many others along the terrace-marsh boundary, is on the last solid ground toward the marsh. In Fig. 36, the view is down the terrace, toward the marsh Tour d'Anglas. This lower part of the terrace was dissected to some extent before Recent marsh encroached upon its surface and buried its seaward portion. Mas de Psalmody is a gravelly hill of terrace material entirely surrounded by marsh, about four kilometers north of Aigues-Mortes, which owes its existence to

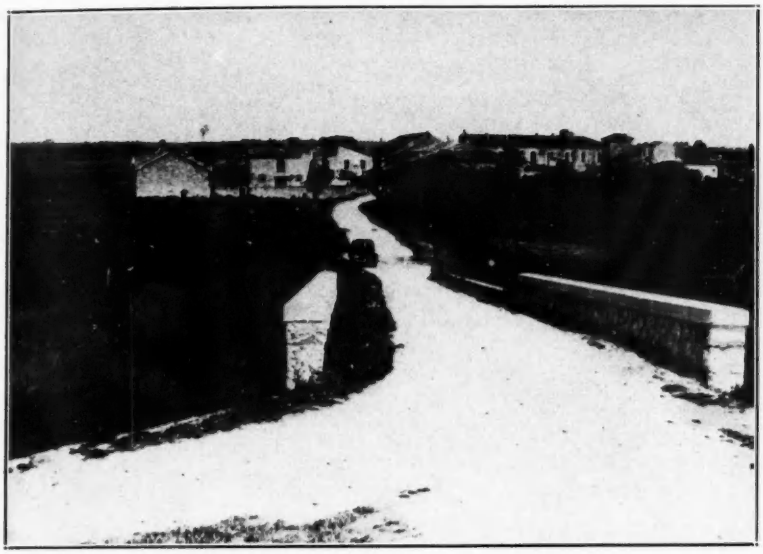

FIG. 35.—The boundary between highest terrace and coastal marsh is very sharp at Franquevaux. The photograph was taken from an overpass across Canal du Rhône à Sète. In the foreground is marsh vegetation. Beyond Franquevaux is the vine covered sloping terrace surface.

the dissected nature of the terrace surface now being surrounded and buried under marsh. Conspicuous dissection also occurs west of St. Gilles. The even surface of the less dissected parts, however, is so striking that the fact of deltaward flexing cannot be seriously questioned.

The deformation of the oldest terrace is more pronounced than that of later surfaces. Low terraces along the Vistre sink and pass beneath marsh deposits at low angles in comparison with that of the older terrace. The record of deltaward flexing clearly indicates subsidence which has been going on over a long period of time. The oldest terrace has shared longest in the movement and is therefore the most inclined, as is the case elsewhere (3–93; 20–461; 70–382; 80–510).

The Quaternary record of downflexing toward the delta is exactly similar to that in Louisiana. The four main terraces of the Rhône, which have been made classic by de Lamothe (63; 64; 65; 67) and Depéret (37; 38), maintain almost constant intervals above the existing flood plain for many scores of miles, but in a very few miles, near the coast, they steepen

FIG. 36.—Highest terrace surface converging with coastal plain. The vineyard in the middle distance is located on the gravel surface of the terrace. To the right is the flood plain of the Vistre. The land in the immediate foreground flanks a meander scar cut when the Vistre was somewhat below its present level and it erodes rapidly for that reason. In the extreme distance a row of trees follows the Canal du Rhône à Sète across the marsh, near Tour d'Anglas.

and plunge beneath floodplain surfaces, exactly as do the four main Louisiana terraces with relation to the existing flood plains of the Mississippi and nearby rivers. The equivalent of 200 miles across Louisiana, with regard to terrace flexing, occurs in less than 10 miles along the lower Rhône.

Subsidence during historical times appears to have been relatively slow but continuous in operation.

Historical records furnish such information as a subsidence of four meters of the old Roman bridge at Arles (91–75), but this matter is open to some question. Floods at Trinquetaille reach levels three meters higher than in Roman times. Old drains into the river would now flood the town had they not been closed by masonry in the 13th century. Roman structures dating from the 2nd and 3d centuries have been found four meters below the flood plain at Saint-Denis, four kilometers south of Beaucaire (105–319). Many old Roman buildings are buried two or three meters

in the vicinity of Arles. Oldham believes that Arles has subsided four or five meters since Roman times (91–80). As the distance from Arles to the margin of the delta has not changed appreciably within historical times the burial of Roman structures should not be regarded as wholly the product of alluviation. Subsidence must be the main cause of burial. To some extent improvements in the artificial levees of the Rhône have prevented burial to normal depths.

It is universally recognized that the Camargue was prosperous in Roman times and produced a surplus of wheat that earned for it the appellation, "granary of the Roman army." The decline in population during the early Middle Ages was more likely due to invasion than to subsidence (14–29). People continued to live in the Carmague and erected beacons to guide navigators along such Rhône courses as the Saint-Ferreol and d'Ulmet channels. By about the 17th century they were applying the various Mas' and Saint's names in use today, but a return to true prosperity awaited the discovery that phylloxera could not invade vineyards planted on its sandy soils (33–430). While some channels have been added and others abandoned and while the shore has advanced in some places and retreated in others, there is no real basis for the belief that the Carmague has undergone much physical change during the last 20 or more centuries. It has not escaped some subsidence, however.

The étangs of the Camargue and adjacent deltaic plains have been maintained by subsidence rapid enough to result in actual submergence of places not sufficiently alluviated to remain above sea-level. Étang de Vaccarès is essentially the delta-flank depression between Rhône d'Ulmet and de Saint-Ferreol. Galéjon is essentially the eastern delta-flank depression of the whole delta, and Stagna, with lowlands leading to Étang de Mauguio, is the western depression. The shift of the Grand Rhône to its present course resulted in the alluviation of Galéjon to a very considerable degree. The great lowland marshes of that region have been sharply reduced in area if we are to accept views of Lenthéric as being reasonably sound with regard to their extent during Roman times (75). Stagna has been to a large degree alluviated by streams west of the Petit Rhône. It is in the central region, between main Rhône distributaries, that displays the most striking evidences of submergence today.

Étang de Vaccarès has fluctuated in importance as an inland sea. A great deal of navigation was carried on during the early Middle Ages but alluviation reduced depths so much that the "ports of the Vaccarès" had to be abandoned in the 12th century (51–13). Without alluviation from nearby Rhône channels depths would have increased, for the evidences of subsidence are clear. Figure 37 shows a wall of Greek or Roman origin,

FIG. 37.—Greek or Roman wall extending toward the waters of Étang de Vaccarès, near Carrelet. Wave erosion has exposed the wall and has removed the alluvium that buried it. The sea cliff is about six feet high nearby. The depth to the base of the wall is unknown, but is certainly below sea-level.

near which coins dating from the 3d century, B.C., have been recovered. This wall now extends to below sea-level and has been exhumed by waves from the Vaccarès. The natural levees nearby, along Rhône de Saint-Ferreol, yield a record of Greek and Roman structures built through a period of eight or more centuries of alluviation at the average rate of nearly one foot per century. This is likely a fair measure of the rate of subsidence, because it is probable that the buildings of any one date were originally elevated about as high above sea-level as those of any other date (Fig. 20).

The étangs marginal to the delta, especially where protected from alluviation under present conditions, clearly indicate the effect of regional subsidence. Étang de Thau, was part of the western delta-flank depression of the Tourradons channel. Now that active courses have shifted to the east the étang is relatively free from alluviation. Its bottom is covered with large banks of oyster shells but its water is today too salty to permit the growth of oysters (98–111). This increase in salinity is a result of submergence. The large étangs south of Aigues-Mortes and in the Petite Camargue have suffered decreased alluviation within the last few centuries,

with the result that they have enlarged considerably. Roughly one-half of the Petite Camargue is now flooded or stands below sea-level. This proportion is in striking contrast with that of land near the Grand Rhône, where less than one-fifth of the surface is in a similar condition.

The recent shift of the Rhône to its existing eastern branch has directed alluviation into the eastern delta-flank depression to such a degree that relatively little flooded surface remains. Subsidence, however, has been active, as is demonstrated by the huge quantities of Greek and Roman pottery and building material now being cast upon the beaches in the vicinity of Anse de Saint-Gervais, near Fos. The depth of the source material is not altogether known, but it is certainly several meters below sea-level.

Artifacts have been found at many places in the Camargue under conditions indicating subsidence (Fig. 19). Near the fortified church at les Saintes-Maries they occur over a meter below sea-level (34–355; 52–389). Denizot minimizes subsidence of the delta region, basing much of his argument on the relatively small depth to this pottery horizon. In connection with his argument it should be pointed out that the pottery is incorporated in an old natural levee and presumably accumulated on the surface near its crest. To the distance the material now lies below sea-level should be added the original height of the natural levee, so that the indicated subsidence is closer to three than to one meter. Material being cast upon the beach at les Saintes-Maries comes from a horizon of unknown depth, probably several meters below sea-level.

The oldest archaeological finds in the Camargue are pieces of pottery exhibiting Greek patterns, with figures in red (52–379). These date from as far back as the 5th or 6th century, B.C., and the finds are widely distributed (14–19), except that no finds have been made in the newer southeastern corner of the delta. Earlier culture history is obscure. The idea has been expressed that Stone or Bronze Age peoples inhabited the Camargue, but no adequate proof of this has been advanced (36–353). It was not until stone was brought to the Camargue for dwellings and until the use of pottery had become widespread that much in the way of records could be left (14–18). This appears to have happened only after the Greeks arrived. Greek remains certainly indicate subsidence.

Anatalia, an old maritime colony in the Vaccarès, is now below sea-level (52–375). At Sainte-Cécile, on the north side of the Vaccarès, coins, charcoal, and lead have been found 2.1 meters below sea-level. At Tour du Vallat, east of the Vaccarès, Roman tile floors have been uncovered at a depth of 2.1 meters below sea-level. Altogether 145 cubic meters of archaeologic material have been recovered at Mas Nôtre Dame d'Amour, Abbe d'Ulmet, and Pâtis de la Trinité, mainly at a depth of about 1.0 meters below sea-level (52–360).

Physical evidence also indicates subsidence in the Camargue. Though this region is not one well located for the accumulation of peat and no significant amount of peat is cut from its surface today, peat or lignitic layers have been reported to depths of at least 27 meters below sea-level (8–502) and there is good reason to believe that they extend to three times that depth (98–102). Brackish water deposits containing *Cardium edule* L., are interstratified with fluviatile materials for a depth of at least 50 meters (34–41). Such a section is clearly one in which the the materials all collected at about sea-level and over a period sufficiently long to accommodate subsidence to an amount equalling their thickness (121–10). Deltas elsewhere always exhibit similar subsurface conditions (77).

COMPARSION BETWEEN RHÔNE AND MISSISSIPPI RIVER DELTAS

From the physical standpoint the chief contrasts between the Rhône and Mississippi River deltas are quantitative. In area of delta proper, as limited by marginal distributary streams the ratio is about 20 : 1. It is curious that the average daily load of sediment received by each delta is roughly in this same ratio (22–216; 106–162). Rhône sediment is far coarser, so that proportionately more extensive areas of sand occur along its recent and ancient beaches and in its crevasse deposits.

Modern geologic time has witnessed striking rearrangements in channel patterns in each delta. The concept, "deltaic coastal plain," is extremely useful in describing the existing plus the recently abandoned parts of each delta. There is little change in general nature of the territory between the delta proper and its marginal coastal plain.

In both deltas it is interesting to note how greatly today's channel pattern depends on the presence of previously existing channels. Reversals in direction of original flow occur along parts of reoccupied channels both in Louisiana and southern France.

Natural levees are the dominant land forms of each delta and their arrangement forms the skeletal ribbing between which the webs of lowland grow that comprise the larger part of the total land area. The lowland is marshy or swampy, consisting of basins that are divisible into smaller and smaller units as one recognizes more and more minute orders of elevations associated with distributary drainage. The least consequential divides are the smallest crevasse deposits and the least consequential basins lie between them. From the crests of main channel levees to the central parts of major basins the sedimentary sequence grades from sands to fine clays. Organic deposits accumulate in the wet marshes and water-filled depressions of the lowest basins.

Both Rhône and Mississippi deltas face tideless seas. Changes in water level result from winds more than from lunar position. Seasonal contrasts in climate, especially the amount and seasonal distribution of precipitation, render the low, clayey basins of the Rhône delta useful as salinas, for the commercial production of salt from sea water. Equivalent areas in the Mississippi delta serve no such useful purpose. The great value of furs, particularly from the muskrat, realized in the freshwater marshes of the Mississippi delta suggests a neglected source of revenue from similar lands near the Rhône. Protection from flooding is accomplished by a dike against the sea along the Mediterranean. Somewhat equivalent features, dikes between flooded marsh and the agricultural lands of individual natural levees, exist in Louisiana but no general barrier has been erected against the Gulf of Mexico and the severity of hurricanes likely renders such a project impractical. Both major Rhône and Mississippi channels are confined between artificial levees during flood stages (94).

Delta-flank depressions are extremely well developed on either side of the Mississippi River delta and pronounced embayments occur between all principal distributaries. The Rhône delta exhibits similar features, but in subdued form. Such contrast as exists in this regard apparently is related to the lesser rate in subsidence of the smaller delta. Where subsidence has been actually measured on well established bench-marks the rate has been found to be most rapid immediately in the vicinity of the places receiving heaviest sedimentary loading. At the mouth of Southwest Pass, of the Mississippi River, the rate is about eight feet per century, under present conditions. At the mouth of the next active river outlet, South Pass, it is about six feet per century and at the Head of Passes, some 20 miles inland, it is but two feet. No evidence from the Rhône delta suggests a rate in excess of about one foot per century at any time within the historic period. Considerable evidence, even along the coast, suggests slower rates.

The reconstruction of sequential modern drainage patterns indicates a decided increase in Mississippi River delta area during the last 20 centuries or so. Similar evidence suggests that the Rhône delta has remained about constant in area, or at least that any gain has been decidedly small. This may reflect the fact that the Mississippi River has alluviated a much more extensive estuary than has the Rhône during the Recent rise in sea-level. The Rhône delta has attained an areal equilibrium which the Mississippi has found greater difficulty in reaching.

The pattern contrast between the "bird's foot" delta of the Mississippi River and the relatively smooth-shored and traditionally deltoid shape of the Rhône delta is certainly not a matter of tideless seas nor is it the result of feebleness in marine currents along delta fronts. The deltas have both

of these conditioning physical factors in common. The contrast may be the result of differences in load, drainage patterns, and rates of sedimentation. Land advances into the sea near the mouth of each outlet channel in both deltas. It retreats under wave attack in both deltas. The conditions of wave attack are about the same in either case. Throughout modern times the Mississippi has tended to follow a single main channel as far as the vicinity of the coast. Its distributaries have been relatively short and sedimentary load has been concentrated over rather small areas. Though subsidence has been rapid in loaded areas the supply of sediment has been sufficient to drive the coast outward in the vicinity of active channels. The Rhône, on the other hand, appears to have had the habit of forming its chief distributary branches a relatively greater distance inland and the mouths have been rather widely separated. Facing a wave attack not unlike that along the coast of Louisiana but supplied with only about one-twentieth as much load and with this load more scattered with regard to places of deposit, the relative importance of wave attack has been such that the Rhône delta distributaries have been unable to send out long "legs" or "claws" of land resembling those of the Mississippi. If the Atchafalaya, the potential "Little Rhône" of the Mississippi, continues to divert an ever increasing proportion of Mississippi River load and discharge, coastal Louisiana may be shorn of its salients by wave attack and the delta may attain a form similar to that of the Nile or Rhône.

The Quaternary and Tertiary geologic hinterland of the Rhône delta is so similar to that of the Mississippi that one familiar with Gulf Coast geology feels tempted to use American formational names for the rocks displayed in southern France. Quaternary terraces, the oldest of which have been identified as "Pliocene?" by many writers in each case, slope toward each delta, as do Tertiary beds below. The known thickening of the post-Mesozoic section in southern Louisiana may well have its counterpart toward the mouth of the Rhône.

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